95th Congress
2d Session

COMMITTEE PRINT

Committee
Print 95—43

U.S. ENERGY DEMAND AND SUPPLY 1976–1985

LIMITED OPTIONS, UNLIMITED CONSTRAINTS

FINAL REPORT

PREPARED BY THE

CONGRESSIONAL RESEARCH SERVICE

FOR USE BY THE

SUBCOMMITTEE ON ENERGY AND POWER

OF THE

COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE

HOUSE OF REPRESENTATIVES

NINETY-FIFTH CONGRESS

FIRST SESSION

MARCH 1978

95th Congress
2d Session

COMMITTEE PRINT

Committee
Print 95–43

U.S. ENERGY DEMAND AND SUPPLY 1976–1985

LIMITED OPTIONS, UNLIMITED CONSTRAINTS

FINAL REPORT

PREPARED BY THE

CONGRESSIONAL RESEARCH SERVICE

FOR USE BY THE

SUBCOMMITTEE ON ENERGY AND POWER

OF THE

COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE

HOUSE OF REPRESENTATIVES

NINETY-FIFTH CONGRESS

FIRST SESSION

MARCH 1978

U.S. GOVERNMENT PRINTING OFFICE

21–616 O

WASHINGTON : 1978

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE

HARLEY O. STAGGERS, West Virginia, *Chairman*

JOHN E. MOSS, California
JOHN D. DINGELL, Michigan
PAUL G. ROGERS, Florida
LIONEL VAN DEERLIN, California
FRED B. ROONEY, Pennsylvania
JOHN M. MURPHY, New York
DAVID E. SATTERFIELD III, Virginia
BOB ECKHARDT, Texas
RICHARDSON PREYER, North Carolina
CHARLES J. CARNEY, Ohio
RALPH H. METCALFE, Illinois
JAMES H. SCHEUER, New York
RICHARD L. OTTINGER, New York
HENRY A. WAXMAN, California
ROBERT (BOB) KRUEGER, Texas
TIMOTHY E. WIRTH, Colorado
PHILIP R. SHARP, Indiana
JAMES J. FLORIO, New Jersey
ANTHONY TOBY MOFFETT, Connecticut
JIM SANTINI, Nevada
ANDREW MAGUIRE, New Jersey
MARTY RUSSO, Illinois
EDWARD J. MARKEY, Massachusetts
THOMAS A. LUKEN, Ohio
DOUG WALGREN, Pennsylvania
BOB GAMMAGE, Texas
ALBERT GORE, Jr., Tennessee
BARBARA A. MIKULSKI, Maryland

SAMUEL L. DEVINE, Ohio
JAMES T. BROYHILL, North Carolina
TIM LEE CARTER, Kentucky
CLARENCE J. BROWN, Ohio
JOE SKUBITZ, Kansas
JAMES M. COLLINS, Texas
LOUIS FREY, Jr., Florida
NORMAN F. LENT, New York
EDWARD R. MADIGAN, Illinois
CARLOS J. MOORHEAD, California
MATTHEW J. RINALDO, New Jersey
W. HENSON MOORE, Louisiana
DAVE STOCKMAN, Michigan
MARC L. MARKS, Pennsylvania

W. E. WILLIAMSON, *Chief Clerk and Staff Director*
KENNETH J. PAINTER, *First Assistant Clerk*
ELEANOR A. DINKINS, *Assistant Clerk*
WILLIAM L. BURNS, *Printing Editor*

Professional Staff

ELIZABETH HARRISON
JEFFREY H. SCHWARTZ
BRIAN R. MOIR
KAREN F. NELSON
ROSS DAVID AIN

CHRISTOPHER E. DUNNE
WILLIAM M. KITZMILLER
MARK J. RAABE
THOMAS M. RYAN
JAMES S. COWEN

LEWIS E. BERRY, *Minority Counsel*

SUBCOMMITTEE ON ENERGY AND POWER

JOHN D. DINGELL, Michigan, *Chairman*

RICHARD L. OTTINGER, New York
ROBERT (BOB) KRUEGER, Texas
PHILIP R. SHARP, Indiana
ANTHONY TOBY MOFFETT, Connecticut
BOB GAMMAGE, Texas
JOHN M. MURPHY, New York
DAVID E. SATTERFIELD III, Virginia
TIMOTHY E. WIRTH, Colorado
ANDREW MAGUIRE, New Jersey
MARTY RUSSO, Illinois
EDWARD J. MARKEY, Massachusetts
HARLEY O. STAGGERS, West Virginia (ex officio)

CLARENCE J. BROWN, Ohio
CARLOS J. MOORHEAD, California
JAMES M. COLLINS, Texas
W. HENSON MOORE, Louisiana
DAVE STOCKMAN, Michigan
SAMUEL L. DEVINE, Ohio (ex officio)

FRANK M. POTTER, Jr., *Staff Director and Counsel*

LETTER OF TRANSMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
Washington, D.C., January 10, 1978.

Hon. JOHN D. DINGELL,
Chairman, Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, Washington, D.C.

DEAR CONGRESSMAN DINGELL: In response to your request, we are submitting the final report of a comparative analysis of U.S. energy demand and supply through the year 1985. The report is entitled: "U.S. Energy Demand and Supply 1976–1985: Limited Options, Unlimited Constraints."

The report provides a brief overview of domestic and international energy demand and supply and emphasizes energy supply constraints.

The following authors participated in the preparation of the report: Warren H. Donnelly, Senior Specialist in Nuclear Energy, Environment and Natural Resources Policy Division; Joseph P. Riva, Specialist in Earth Science, Science Policy Research Division; Herman T. Franssen, Specialist, Environmental Policy, Environment and Natural Resources Policy Division; Paul Rothberg, Analyst in Science and Technology, Science Policy Research Division; Robert Morrison, Specialist in Ocean Policy, Science Policy Research Division; David Hack, Analyst in Science and Technology, Science Policy Research Division; and, Howard Useem, Economic Analyst, Economics Division.

We hope that this report will serve the needs of your Subcommittee as well as those of other committees and Members of Congress.

Sincerely,

GILBERT GUDE,
Director, Congressional Research Service.

CONTENTS

TABLES

TABLES—Continued

FIGURES

SUMMARY

U.S. ENERGY DEMAND AND SUPPLY, 1976–85: LIMITED OPTIONS, UNLIMITED CONSTRAINTS

(By Dr. Herman T. Franssen, Specialist in Environmental Policy, Congressional Research Service)

INTRODUCTION

At a time when Congress is considering the most dramatic step forward in shaping the Nation's energy future, it may be useful to take another look at the problems associated with increasing domestic energy supply, even if energy growth rates are experienced which are considerably below the historical experience of the past few decades.

Only a few years ago, the National Petroleum Council (1972) and the Federal Energy Administration (1974) produced multivolume studies indicating that the United States could be energy self-sufficient by 1985 at energy growth rates which are now considered much too high by most energy analysts. These and a number of other studies provided optimistic supply pictures for all major sources of domestic energy supply (oil, gas, coal and nuclear) and some nonconventional energy sources (such as synfuels) as well. Today, almost exactly 3 years after the publication of FEA's Project Independence, many of our earlier hopes have been shattered by the same agencies that only a few years ago showed us the way to the promised land. Most energy studies published in 1976 and 1977 have been far less optimistic on domestic supply of almost all energy sources than earlier studies. What brought about this change of mind?

In the first place, revised estimates of oil and natural gas resources by the U.S. Geological Survey and several oil companies led to lowering future production expectations. This was later compounded by Government delays in leasing Federal lands for fossil fuel exploration and development. Earlier optimism about the future of nuclear power was replaced by pessimism as electric utilities canceled scores of power plants, ordered at a time when cost considerations were more favorable, and public opposition to nuclear power was still in its infancy. Careful analyses of the numerous constraints on the development of synfuels caused projections of the future contribution of synfuels to the National energy supply to be reduced by several orders of magnitude.

The area of most intense debate today is on the future coal use. Is it possible that the recent pessimistic coal use projections for the United States by the Congressional Research Service, the General Accounting Office, the Office of Technology Assessment and others have been too pessimistic? Did these agencies and others overlook the economics of coal use and overemphasize the environmental and other problems limiting demand and supply? It is probably too early to say whether the coal use figures in the National Energy Plan are too high or not, but it may serve a purpose to examine carefully all con-

straints on coal demand and supply. That way Government might be in a position to change direction midcourse to prevent yet another supply shortfall in this area.

Energy demand

A number of recent U.S. energy forecasts by Government agencies, academic institutions, and private industries compared in this study have arrived at surprisingly similar energy demand projections for the United States in 1985.

Most of these studies project that U.S. primary energy consumption will rise from about 74 quadrillion Btu (Q) in 1976, to between 81 and 85 Q in 1980; between 91 and 104 Q in 1985; and, between 105 and 116 Q by 1990. Given different assumptions on economic growth rates and on energy demand elasticity, the difference between the high and low figures (5 percent in 1980; 13.5 percent in 1985; 11.1 percent in 1990) are very small. Many other studies on U.S. energy demand not analyzed in this report (OECD/IEA, World Energy Outlook 1977; W. J. Levy, An Assessment of U.S. Energy Policy, 1976, and others) confirm this general trend in rising U.S. energy demand.

Oil and natural gas supply

In response to a CRS questionnaire on oil production projections through the year 1990, 12 of the 15 largest integrated oil and natural gas companies operating in the United States provided valuable insight in industry views of future oil and gas production under a set of favorable economic and political assumptions. While individual companies within the industry differed in their outlook on future production, eight of the twelve were close to the mean 1985 production level of 10.9 million b/d or crude oil and natural gas liquids, and the 16.9 trillion cubic feet (TCF) per year of dry natural gas, used in the base case of CRS's Project Interdependence.

Underlying these production estimates are the following assumptions: (1) decontrol of oil by June, 1979 (EPCA expires); (2) no windfall profit taxes added after that date; (3) no changes in the 1954 OCS Lands Act; (4) average annual leasing of 1.5 to 2 million acres of OCS lands for exploration and development; and (5) no vertical divestiture.

The 10.9 million b/d of oil production and 16.9 TCF per year of natural gas production in the CRS base case are relatively close to other major energy supply assessments by the Central Intelligence Agency, the Executive Office of the President (National Energy Plan), the Department of Commerce, the International Energy Agency (OECD), and many other estimates. The Federal Energy Administration projected significantly higher levels of oil and gas output in its 1974 and 1976 forecasts, but the draft version of the 1977 National Energy Outlook was more in line with the other studies quoted here. Most of the studies assumed no change in the real price of world oil through 1985 in their base case projections.

While it is clear that because of the complexity of the matter and the numerous unknowns, nobody can forecast 1985 oil and gas production with any degree of accuracy, it is important to consider the geological, technical, economical, and institutional barriers that must be overcome to achieve a production target of close to 11 million b/d by 1985 (CRS NEP and other projections).

The resource base and drilling effort needed to support a U.S. oil production of 4 billion barrels per year in 1985 (about 11 million b/d) can be determined as follows: (1) assuming a gradual increase of production about 34 billion barrels of oil will need to be produced from 1977–85 to achieve the 1985 production target; (2) another 40 billion barrels of oil reserves will be needed to maintain the current reserve to production ratio of 10 years. Lowering this ratio will cause more problems in the future. One should keep in mind that physical constraints generally limit annual withdrawal to an amount equal to a production-to-reserve ratio of approximately 1:10. This is an aggregate ratio; individual fields will vary above and below that ratio. Hence we are currently producing about the maximum allowable from our proved reserves of about 30 billion barrels 3 billion barrels of oil per year (crude oil only; NGL not included).

The total domestic petroleum needed by 1985 to attain a production of 4 billion barrels (about 11 million b/d) and maintain a desirable reserve-to-production ratio of 10:1, would be about 74 billion barrels. Liquid petroleum reserves (crude oil and natural gas liquids) at the end of 1976 totaled 37.3 billion barrels, and another 3 billion barrels could be added for oil produced with advanced recovery techniques (estimate by the National Petroleum Council). Thus, another 36.5 billion barrels (74.1 − 37.6) will have to be added to reserves by 1985 to support the 4 billion barrels for that year, while maintaining a 10 to 1 reserve ratio.

A part of this will come from revisions and extensions of existing fields (inferred reserves), but by 1985 most of the oil will have to come from new fields. In order to meet the desired production of 4.0 billion barrels in 1985 (with a 40 billion reserve at the end of that year), it will be necessary to add about 4 billion barrels per year for the next nine years. The maximum to be expected from enhanced recovery from old wells in 1985 is 0.6 billion barrels (high estimate by National Petroleum Council for 1985). Since 1948, there has only been one year that reserves have increased by more than 3 billion barrels (1971 Prudhoe Bay). In the absence of such fortunate finds of giant fields in the frontier areas, it will be very difficult, if not impossible, to reach the 4 billion barrels projection for 1985 production. In recent testimony before the Senate Committee on Finance, Charles D. Masters, Chief of the Office of Energy Resources of the U.S. Geological Survey, said that to keep production at current levels would be a prodigious task for industry, and to increase production over and above present rates would take Herculean efforts that in the end might not be successful. Several Prudhoe Bay type finds may be needed to reach a 1985 production of close to 11 million b/d.

Natural gas

In a recent industry survey on natural gas production projections through 1990 conducted by the Congressional Research Service, the mean 1985 production figure based on estimates of 12 of the 15 largest oil and gas producing companies in the United States amounted to 16.9 TCF.[1] The same production level was projected for 1990. Assump-

[1] The CRS projections of natural gas production for 1985 represent domestic dry gas to domestic use, a term used by the Bureau of Mines in its annual natural gas production statistics. It represents the dry natural gas after all the liquids have been taken out of the porduced wet gas, and transmission losses, storage, and exports are accounted for.

tions underlying the forecasts were largely similar to those for the oil output projections (see p. 3). In addition, early decontrol of new natural gas was assumed.

The 16.9 TCF of likely natural gas production in the CRS study is almost identical with earlier findings b ythe Bureau of Natural Gas of the Federal Power Commission (projections of 1985 output of 16.75 TCF by Gordon Zareski in 1977). Studies by the General Accounting Office, the Executive Office of the President (NEP), the CIA, and a number of studies by private industries and consultants are within 5 to 10 percent of the CRS estimates. The high natural gas supply case in the CRS study envisions a production of about 17.5 TCF in 1985, and the low supply scenario projects an output of 15.7 in 1985. The CRS high production estimate for 1985 is about 5 percent below the projected 1977 dry natural gas output of 18.6 TCF.

To arrive at a dry gas production of 17.5 TCF in 1985, the following resource base will be required: (1) about 160 TCF of gas must be produced between 1977 and 1985 to arrive at the projected 1985 output level of 17.5 TCF; and (2) about 210 TCF will be needed to maintain a 12 to 1 reserve-to-production ratio. Some of this gas will come from extensions and revisions of known fields and possibly from nonconventional sources of methane, but an average of 17.2 TCF will have to be added each year for the 1977–85 period. Not since the North Slope discoveries has more than 17.2 TCF been added to reserves in any one year. In fact, in the lower 48 States additions to reserves have averaged only 8.6 TCF per year in the 8 years between 1968 and 1976 (resulting in declining production since 1973/74).

It would appear that even with a marked increase in drilling, the drawing down of the gas reserves below the 12:1 reserve-to-production ratio, and some development of nonconventional sources of methane, maintaining a level of natural gas production of 17.5 TCF per year will be very difficult. It is probable that discoveries of giant gas fields in frontier areas would be necessary to meet this projection. In order to meet the 1985 output of 17.5 TCF with a 12:1 reserve-to-production ratio, about one-third of the undiscovered recoverable resources of natural gas (USGS Circular 725) will have to be found between now and 1985.

Coal

For at least the next 100 to 150 years, the United States will have enough coal to meet projected domestic and foreign demand. Domestic coal use grew rapidly through the 19th century, slowed down until the middle 1940's when it peaked. Coal use actually declined between 1945 and 1960 due to the availability of relatively cheap and clean liquid fossil fuels. Only in recent years has coal consumption again reached the high level of the middle 1940's.

Quadrupling of the price of imported oil following the 1973/74 oil embargo; growing uncertainty about access to foreign oil; reduced domestic oil and gas prospects; higher prices of domestic oil and gas; serious constraints on nuclear power development; and, government policy to shift industrial users from oil and gas to coal, have all contributed to the renewed interest in and long-term prospects of coal use in the United States.

While past efforts by the FEA to force electric utilities to convert to coal wherever possible (ESECA, 1974) have failed, pending legis-

lation will make it exceedingly difficult for new electric utilities and large industrial plants to use gas or oil as a boiler fuel. The regulatory process will reinforce the ongoing industrial response to higher oil and gas prices and uncertainty of future oil and gas supply.

Few energy analysts will deny that coal use has a bright future in the United States, but most will agree that numerous problems associated with both the demand for and supply of coal are likely to slow down domestic coal use to well below the 1,175 million tons projected in the National Energy Plan. In the first place, demand for electrical power could be substantially below the level projected in the NEP because electric demand may be lower and environmental constraints may slow down their development. Second, it way not be realistic to assume that major conversion of existing oil and gas burning facilities to coal will have taken place by 1985, unless industry is really forced to do so. Third, there are a number of important constraints on expanded coal use such as: (1) air quality standards; (2) strip mining provisions; (3) trained manpower shortages for deep mining; (4) poor labor relations; (5) continued lowering of productivity, in part caused by new health and safety standards set by the Government; (6) transportation bottlenecks; (7) potential shortages of some mining and pollution abatement equipment; (8) delays in Federal leasing of coal lands; (9) water use problems in the West; (10) institutional problems, in particular in the West.

In view of these constraints, the GAO, the OTA, the Congressional Research Service, and several others, nongovernmental research organizations have projected that U.S. coal production is likely to fall short of the 1985 target of 1.265 million tons in the National Energy Plan by several hundred million tons (to below 1 billion tons per year).

Nuclear power

Continuing controversy about the future of nuclear power for the generation of electricity clouds the future of this industry. At issue are the economics of nuclear power and the risks which some critics perceive to the public health, safety, environment, national security and world peace. The United States possesses the world's largest industrial base for civil use of nuclear power, but several parts necessary for the continued or expanded long-term use of nuclear power are still missing. Since proposals to impose a national moratorium nuclear power have yet to succeed, it appears that the principal policy questions for the future supply of nuclear power are how much more nuclear generating capacity should be provided, if any, where, and when.

Beginning with modest projections in 1962, succeeding forecasts rose quickly to peak estimates in 1973 and 1974, and then fell precipitously in the aftermath of the Arab oil embargo of 1973–74. The most optimistic forecast in 1973/74 anticipated as much as 2,000 gigawatts of nuclear power by the year 2000. Within 3 years these had dropped to Secretary Schlesinger's latest figure of 380 gigawatts by the turn of the century. The latter is slightly below the accelerated scenario of FEA's Project Independence report for 1985. In view of the past record of nuclear forecasting, projections of nuclear power capacity beyond a few years are by no means written in stone. Actual and potential constraints on nuclear power expansion include environmental and safety problems related to the nuclear fuel cycle, facility

siting, high cost of construction, public acceptance, and drawn-out licensing schedules.

The National Energy Plan has estimated that nuclear power under the plan would provide the energy equivalent of 3.8 million b/d of oil by 1985 (3.6 million b/d without the Plan), or the equivalent of 141 gigawatts operating with a capacity factor of 65 percent. In the plan, nuclear power serves as a supplement to coal to fill the gas between energy demand and a projected relatively stable production of oil and natural gas. Since April, 1977, the FEA, ERDA and NRC have further reduced probable nuclear power capacity in 1985 to 113 gigawatts with an energy equivalent of 3 million b/d of oil.

Other domestic energy sources

Of the numerous alternative energy sources for the future, geothermal and in particular solar energy have good prospects of making a commercial contribution to energy supply between now and 1985. Solar energy has received a great deal of attention in recent years, but in spite of its great promise for the future, the immediate payoff is not likely to be very large in the intermediate future. Even with substantial Government support, most analyses indicate that solar energy will contribute no more than 1 percent of total U.S. energy demand in 1985 and 2 percent by 1990.

Conventional hydropower now provides about 15 percent of the electric generating capacity in the contiguous United States. In view of the long leadtimes, hydropower plants being planned now are not likely to contribute to the 1985 supply of energy. Substantial capacity remains to be developed in the future.

Projections of U.S. energy demand and supply through 1985

In the base case of Project Interdependence, CRS assumed real annual economic growth rates of 3.5 percent for the period from 1976–90. This growth rate is necessary to reduce unemployment from the current 6.9 percent to about 5.5 percent (the average unemployment rate between 1965 and 1974 was 4.6 percent). Energy demand growth, estimated at 2.9 percent per year, is based on substantial increases in the real price of oil and natural gas (about 50 percent for oil and 100 percent for natural gas for the period through 1990). Total energy demand by 1985 under those price assumptions is projected at 94.7 quadrillion Btu or 44.8 million b/d. The National Energy Plan, under different assumptions, projects total energy demand in 1985 at 46.4 million b/d oil equivalent. In table 1, both the CRS and NEP's demand projections are labeled "desired demand," suggesting that supply constraints may force world oil prices beyond the levels projected in the CRS and NEP analyses. If that happens, energy demand, GNP growth rates and employment are likely to be reduced.

On the supply side of the equation, a careful inventory of future oil and natural gas production suggests that in order to keep production at current levels, average annual additions to oil and gas reserves must increase by about 50 percent over the experience of the past 10 years (oil production averaged about 3 billion barrels per year and reserves added averaged only 2 billion barrels during the past decade. Natural gas production averaged 20.7 TCF per year, and reserve additions averaged only 11.5 TCF per year).

TABLE 1.—U.S. ENERGY DEMAND AND SUPPLY PROJECTIONS FOR 1985

[In conventional units and million barrels per day crude oil equivalent]

	Scenario I: Planning base		Scenario II: Possible supply	
	Conventional units	Million barrels per day oil equivalent	Conventional units	Million barrels per day oil equivalent
Total primary energy demand (desired demand):				
CRS, Project Interdependence, base case [1]		44.8		44.8
National energy plan		46.4		44.6
Domestic energy supply:				
Oil and NGL [2]	9.5 million barrels per day	9.5	10.9 million barrels per day.[3]	10.9
Natural gas (dry gas to domestic use).[4]	16.9 trillion cubic feet	8.1	17.6 trillion cubic feet [5]	8.5
Coal (domestic use only) [6]	855 million short tons	8.9	965 million short tons [7]	10.0
Nuclear power [8]	113 gigawatts	3.0	126 gigawatts [9]	3.4
Hydro/geo/solar		1.9		1.9
Total domestic supply		31.6		34.8
Oil and natural gas imports:				
Natural gas	2.1 trillion cubic feet	1.0	2.5 trillion cubic feet [10]	1.2
Oil (including 0.3 million barrels per day for storage).	12.7 to 14.3 million barrels per day.	12.7–14.3	9.2 to 10.8 million barrels per day	9.2–10.8

[1] Assumes 3.5 percent average annual GNP growth rates and 2.9 percent energy growth rates; 50 percent increase of oil price through 1990; doubling of natural gas price through 1990.

[2] CRS, Project Interdependence, low supply case. Requires a 50-percent increase of finding rates through 1985 (compared with finding rates of past decade). See also memo by the Comptroller General of the GAO to the President of the Senate and the Speaker of the House of Representatives, dated Oct. 14, 1977.

[3] Assumes that oil reserve additions will almost double between 1977 and 1986 compared with the previous decade. Based on CRS Project Interdependence, base case under optimistic economic and political assumptions.

[4] CRS, Project Interdependence, base case (based on mean figure of production estimates under favorable political and economic criteria by 12 of the largest oil and gas producing companies in the U.S.). See also GAO and OTA critiques of the national energy plan. Several oil companies, including Exxon, Shell, and British Petroleum project lower volumes of natural gas output for 1985 in their base case scenarios.

[5] Assumes slight higher natural gas finding rates than projected in scenario I. Based on CRS Project Interdependence, high natural gas supply case.

[6] CRS, Project Interdependence, base case (700,000,000 tons for utilities, which is comparable to FEA's National Energy Outlook of 1976 for 1985; assumes industrial use by 1985 of only 160,000,000 tons, which would mean virtually no coal conversion in that sector). CRS base compares with the mean coal use figure in the recent GAO coal study, with the MIT/WAES likely scenario for 1985, and with a recent study on coal use by the Institute for Energy Analysis at Oak Ridge. Assumes adherence to Clean Air Act provision for all new coal-burning facilities.

[7] Assumes considerable exemptions of provisions in the Clean Air Act, and that several other constraints and demand and supply of coal will be removed.

[8] July 1977 estimate of probable 1985 capacity by FEA/ERDA/NRC.

[9] Assumes speeding up of construction of nuclear powerplants.

[10] Assumes approval of additional LNG projects over and above those that have already been approved by the FPC.

In our probable energy supply scenario in table 1, 1985 oil production has been kept at current levels of 9.5 million b/d, and natural gas production has been reduced to the base case scenario of CRS's Project Interdependence, which projects a 1985 dry natural gas production of 16.9 TCF (less than 10 percent below current output).

Recent estimates by the General Accounting Office, the Office of Technology Assessment, and some industrial sources, tend to confirm the above projections of oil and natural gas output for planning purposes.

Domestic coal use is not subject to reserve or resource constraints; at least not for the next century or longer. Coal use is hampered by environmental constraints on burning this fossil fuel in many parts of the country. It is not unreasonable to expect lengthy litigation between environmentalists and industrial coal users, which at best are likely to slow down the expansion of coal use in electrical power plants and industries below levels projected in the National Energy Plan (1.1 billion tons domestic coal use). This, in turn, will delay investments in the coal mining industry. In view of these, and numerous other con-

straints on coal demand and supply, studies by the Congressional Research Service, the General Accounting Office, the Office of Technology Assessment and several other sources, express serious doubts that a coal production level of 1 billion tons (including about 75 to 85 million tons of exports) will be achieved in the United States by 1985. For planning purposes it is prudent to suggest that coal use in the United States will increase from about 600 million tons in 1976 to about 850 million tons by 1985 (CRS, Project Interdependence, base case; GAO, U.S. Coal Development, Promises, Uncertainties, between the low and high coal use scenarios), and that major efforts are needed to remove the numerous obstacles that stand in the way of achieving a higher level of coal use in the United States in 1985. Provisions in the NEP by themselves are no guarantee that projected coal use figures will indeed be achieved.

Nuclear power capacity projections in this study are based on the latest (July 1977) data by the former Federal Energy Administration, ERDA, and the Nuclear Regulatory Commission. Estimates of hydropower and other energy sources are based on the CRS "Project Interdependence" study.

Coal use projections: Rising expectations; a word of caution

Studies by the Congressional Research Service, the Office of Technology Assessment, and the General Accounting Office, on coal use projections in the United States, do not say that it is physically impossible to utilize one billion tons of coal or more by the middle 1980's. They do, however, clearly show the potential contradictions between implementation of environmental legislation and the desire to burn that much coal in the United States. They also caution that numerous other coal use constraints should not be casually brushed aside, but instead, seriously studied and acted on if necessary. There are too many recent precedents to question initially the validity of inflated energy supply projections. Exaggerated supply estimates for oil, natural gas, nuclear power, shale oil and some other energy sources, made by various government agencies and private organizations during the past decade, have all been abandoned in favor of more realistic and lower forecasts.

Probable or possible domestic supply

Scenario I, the planning base, represents the volume of domestic energy supply the Nation can count on with a fair degree of certainty. One should realize, however, that the oil and natural gas output projected in this scenario still requires a major effort in terms of additions to reserves. This scenario also does not represent the lowest projected nuclear capacity and coal use figures. Nuclear capacity by 1985 could decline further due to additional plant cancellations or construction delays. The coal use figure of 855 million short tons in this scenario is still about 50 to 100 million tons higher than the low coal use scenarios in the GAO, CRS, and IEA (Oak Ridge) studies. Hence, scenario I represents across the board a little more than what one might call a "business-as-usual" case.

Scenario II, the possible supply case, represents an optimistic—though under certain conditions a probably attainable—domestic supply case. In addition to a favorable economic climate, it would require

early successful exploration and development of frontier areas where most of the potentially remaining large oil and gas accumulations are likely to be. It would also require substantially higher coal use by both electric utilities and industries. In order to achieve this high level of domestic coal use (comparable to FEA's National Energy Outlook of 1976 and the draft version of 1977), numerous constraints on coal use must be removed, and litigation in the courts would hopefully be limited. As far as nuclear capacity is concerned, it would require speeding up of construction of about 10 plants already under construction. Finally, this scenario is a little bit more optimistic on natural gas imports from Canada and Mexico, which with LNG, could bring total natural gas imports to a level of 2.5 TCF in 1985.

Cost of acquisition of oil and gas imports in constant 1976 dollars

Assuming the real price of oil does not change between 1976 and 1985, projected imports in scenario I would cost between $62.1 and $70.1 billion by 1985 (constant 1976 dollars). This assumes an average cost of crude oil per barrel F.O.B. export terminal of $12.40. Natural gas is priced at its crude oil equivalent. Transportation costs would add an average of about $1 per barrel.

Under similar assumptions, oil and gas imports projected in scenario II would cost the Nation between $47 and $54.2 billion per year by 1985. In comparison, U.S. imports of oil and natural gas in 1970 was about $3 billion. This rose to about $26 billion in 1975 and may be close to $40 billion this year.

What price and demand levels will prevail?

Under domestic energy supply scenario I, oil imports could rise to between 12.7 and 14.3 million b/d by 1985 (see table 1). This would put heavy pressure on free world supply of oil, and in particular on Saudi Arabia. In Project Interdependence, CRS projected free world demand for oil to rise from 40 million b/d in 1976 to 68.8 million b/d (including oil storage) in 1985. U.S. oil imports in the base case of Project Interdependence were projected at 12.3 million b/d (including storage), or between 0.4 and 2 million b/d lower than the scenarios in this study. The difference is due mainly to more optimistic assumptions on domestic oil production.

Under the slightly more optimistic outlook on domestic U.S. supply of oil OPEC nations would be required to produce some 42.8 million b/d in 1985. Given limitation on production based on reserves, current prospects of reserve additions and existing government policy in some OPEC countries on production limits, CRS designed a demand balanced scenario of free world supply and demand of oil and natural gas liquids (table II). In this scenario, Saudi Arabia is counted on to meet much of the increased world demand for oil by expanding production from less than 10 million b/d in 1977 to 16.6 million b/d in 1985. At current levels of output, Saudi Arabia already runs a vast balance of trade surplus. The country would like to bring oil production more in line with its foreign exchange needs, but policy makers are aware that limiting output would result in substantial world oil price increases which, in turn, may retard world economic growth and destabilize much of the free world.

21-616 O - 78 - 2

TABLE II.—DEMAND BALANCED SCENARIO OF FREE WORLD SUPPLY AND DEMAND OF OIL AND NATURAL GAS LIQUIDS

	1980	1985	1990
Demand:			
Consumption	54.8	66.9	76.3
Oil storage	1.9	1.9	
Total demand	56.7	68.8	76.3
Supply:			
United States	10.4	10.9	11.4
Canada	1.5	1.4	1.7
United Kingdom	2.1	2.8	3.5
Norway	.9	1.3	1.6
Other OECD Europe	.3	.5	.5
Other developed countries	.4	.4	.4
Subtotal, OECD and other developed countries	15.6	17.3	19.1
Non-OPEC LDC's:			
Mexico	1.6	3.0	4.0
Latin America	1.4	1.4	1.2
Middle East	.7	.9	.9
Africa	1.2	1.4	1.2
Asia	.5	1.0	1.0
Subtotal, non-OPEC LDC's	5.4	7.7	8.3
OPEC:			
Venezuela	2.2	2.1	2.0
Ecuador	.2	.3	.3
Indonesia	1.8	2.0	2.2
Algeria	1.1	1.1	1.0
Libya	2.2	2.2	2.3
Nigeria	2.2	2.4	2.5
Gabon	.2	.3	.5
Iran	6.5	6.7	6.5
Kauwait	1.8	2.1	2.5
Iraq	2.8	4.0	5.5
United Arab Emirates	2.3	2.5	2.5
Qatar	.5	.5	.5
Saudi Arabia	11.8	16.6	20.6
Subtotal, OPEC	34.6	42.8	48.9
Net exports, Soviet bloc	.6	0	0
Net exports, Peoples Republic of China	.5	1.0	0
Net exports, Communist bloc	1.1	1.0	0

If the Saudis decide to increase production to meet world oil demand at current prices, the CRS study suggests that Saudi income from oil will rise rapidly throughout the 1980's. If, on the other hand, the Saudis will limit output, their action is likely to result in higher world oil prices. While this action would have a negative effect on economic growth rates elsewhere in the free world, Saudi income would still continue to grow and at lower volumes of oil sales. Hence, the narrow national economic interest of Saudi Arabia might dictate only limited further oil production expansion (if any at all). However, the level of Saudi Arabia oil production is not determined by internal economic needs only. Saudi Arabia is aware of its particular role in the world economy, and has acted in the past as a moderator in the OPEC oil price debate. Saudi officials have made it clear in public pronouncements that they are not likely to limit oil production to domestic capital needs, and that oil output may continue to increase in the future. The country is in fact embarked on a program of adding additional capacity to meet oil production levels several million b/d higher than they are currently producing. As a *quid pro quo* government spokesmen have called for Western (in particular U.S.) assistance in bringing about an early settlement to the Middle East conflict, em-

ploying U.N. resolutions 238 and 242 as a basis of the negotiations. Furthermore, the Saudis want progress in the "North-South" debate on the New Economic Order, and U.S. and other developed country assistance in the modernization of their economy. A combination of domestic economic, national security, and foreign policy considerations will influence future oil output in Saudi Arabia. If the United States wants to maintain optimum independence in foreign policy making, the Nation cannot rely on other nations' decisions to expand, maintain, or contract oil output.

However, if the United States does not succeed in limiting its dependence on imported oil to at least the 9.2 to 10.8 million b/d in scenario II, resulting OPEC pressures to increase the real price of oil significantly above current levels, might be too difficult for the Saudis to resist. Substantially higher real world oil prices in the early 1980's, may retard economic growth to the extent that unemployment in the industrial countries could become a social and political problem of almost unmanageable proportions.

Hence, we are facing a world situation of growing uncertainties and growing disparity in short-term economic interests. It is in the narrow economic interest of OPEC to increase the price of oil to the level the market can bear in the long run (opportunity cost to find the marginal barrel of oil or to develop alternative energy sources. If OPEC nations were to follow this policy, significantly higher world oil prices (almost twice current world market price of oil) would retard economic recovery in the industrial nations, and make it more difficult to develop alternative energy systems and/or replace inefficient capital goods for more efficient, energy-saving capital goods. Depressed levels of economic activity in the industrial world will, in turn, slow down economic development around the world.

If, on the other hand, prices of oil are kept at current levels for the foreseeable future, economic growth can continue at a higher level until world oil production peaks. At that point, prices would rise rapidly, making synfuels and other alternative energy sources competitive. Unfortunately, leadtimes are such, that close to a decade is needed for the development of most alternative energy sources. The industrial countries can ill afford to wait for the development of those energy sources until world oil prices have reached the price level of the substitutes. In fact, if they did, the price of synfuels and other alternative energy sources would rise further, because of the higher cost of capital goods needed to develop the alternative energy sources.

Moreover, it would appear that while higher prices of energy will have the positive effect of short-term and long-term energy conservation, another doubling of the price of world oil to reach the price level of some substitutes such as shale oil or oil from tar sands, may depress the economy to the extent that resulting uncertainty about the future of the economy might impair the very investment in alternative energy sources needed to replace dwindling available conventional oil resources.

An agreement with OPEC nations to keep oil prices constant (in 1977 dollars, or allowing for small gradual real increases in the price of oil beginning in the early 1980's), coupled with an aggressive policy of conservation and interfuel substitution, might buy enough time to develop alternative energy sources (synfuels, solar, etc.) provided sub-

stantial government assistance in one form or another will initially be made available. Current world oil spare capacity will make it difficult (for political reasons) to implement such a policy now, but failure to act soon would predictably exacerbate future transition away from oil to alternative energy sources. The Government is in a position somewhat similar to that of a physician with a seriously ill patient who feels in fine shape and is in no mood for a major operation. The doctor can administer some medicine in the hope that his diagnoses is wrong, but knowing that it will not work if his diagnoses is correct, he suggests surgery. He informs his patient that an early operation involves some dangers, but if the illness is indeed as serious as he diagnosed, postponing the operation for several years will call for more drastic and dangerous action later. The physican can only inform his patient of his choices and can administer minor treatment until the patient has consented to the operation.

It is difficult to foresee the extent of OPEC oil price increases under the scenarios discussed here. Under the worst conditions, failure to design and implement an energy policy in the United States which will bring energy demand and supply more in balance than is suggested in this analysis (scenario I), could endanger the Nation's national security, the world's monetary system, world economic growth, and could eventually shake the very social and political foundations of the nations of the free world.

As a nation, we may have to examine more carefully the actual and potential interrelationships and conflicts between our economic, energy, environmental (in the broader sense of the word) and national security goals. Those targets have frequently been arrived at independent of each other. In the end we may find that the current balance (or inbalance) between those goals is not necessarily in the best long-term interest of the country. In that case tradeoffs are called for which may lead to achieving less than the maximum targets we are currently aiming at in each one of these four areas of national interest.

Methods of Forecasting and Planning

(By David B. Hack *)

ENERGY POLICY AND ENERGY TECHNOLOGY

In establishing an energy policy, including a plan to develop new technologies which will use previously unused or underused energy resources, it is important first to understand fully the general energy policies that are available now, without development of new technology, and the full range of benefits or effects obtainable by more scientific selection of currently available general energy and economic policies. In the last two decades, policymakers have placed increasing reliance on a technique of analysis which permits direct use of quantifiable data, assembled and applied according to explicit assumptions, to indicate what will happen under varying conditions. This technique is variously called modeling, or mathematical modeling, or econometric modeling. Disregarding adjectives, modeling is more ubiquitous than casual use of the term discloses.

> Nearly everything economists [or physicists, or engineers, or politicians] do involves some sort of "model." These models may be relatively undefined and not explicitly stated or they may be highly structured mathematical systems.[1]

ENERGY "DEMAND" STUDIES TO 1975—LIMITATIONS OF MODELS USED

A Congressional Research Service report[2] prepared for the 94th Congress examined fifty energy forecasting and planning studies published between 1960 and 1975. The report concluded that, taken as a group, the so-called energy "demand" studies covered (and by implication the models used therein) suffered from certain inadequacies and inconsistencies:

> Most studies do not clearly specify whether they intend to forecast what future energy consumption actually will be or what future energy consumption should be. The confusion which exists is best illustrated by studies interchangeably using the terms (a) energy consumption, (b) energy demand, (c) energy needs, and (d) energy requirements.
>
> *　　*　　*　　*　　*　　*　　*
>
> Most energy forecasts are based on projected historical rates of energy consumption, and accordingly can be criticised for not offering a comprehensive analysis of the equilibrating of energy supply and demand [by which quantities consumed are determined]. Among the exceptions are the 1974 Federal Energy Administration study and the 1975 Hudson and Jorgenson study.
>
> *　　*　　*　　*　　*　　*　　*

---

*David B. Hack is an Analyst in Science and Technology at the Congressional Research Service.

[1] U.S. Library of Congress. Congressional Research Service. Some Strengths and Limitations of Using Economic Models for Policy Analysis [by Warren E. Farb, Specialist in Macroeconomics]. Multilith 77-118 E, May 18, 1977. p. 1.

[2] Energy Demand Studies—An Analysis and Comparison [by the Congressional Research Service, Science Policy Research Division]. In: U.S. Congress. House. Committee on Interstate and Foreign Commerce. Subcommittee on Energy and Power. Pt. 7—Middle- and Long-Term Energy Policies and Alternatives. Appendix to hearings, 94th Cong., 2d sess., Mar. 25 and 26, 1976. 82 p.

Forecasts of energy [consumption] levels required to sustain a prospering economy should be based on a well-reasoned analysis of the relationship between energy consumption and Gross National Product. Instead many studies simply use a correlation or ratio analysis of the historical relationship between energy consumption and GNP.

* * * * * * *

In order to be truly useful to policymakers, energy studies should attempt to appraise the benefits of future levels of energy consumption relative to the costs of providing those levels of energy consumption. This type of balancing analysis is essential to comprehensive policy determination. But regardless of the feasibility of developing such a subjective [or "planning"] form of analysis, studies must avoid the commonly found technique of mechanically projecting historical trends and indicating they are likely to be followed in the future.[3]

The 1976 CRS report cited above covered studies published through mid-1975. Since that time, several other studies have been published, and a selection of these recent studies is summarized below under the title "The Demand for Energy—An Overview of Six Studies." As the cited 1977 CRS report suggests, "* * * models [such as those used in the above-described studies] may be relatively undefined and not explicitly stated or they may be highly structured mathematical systems."

The remainder of this chapter attempts to construct a general policy planning framework in which such studies could be appraised, and defines a single characteristic—the elasticity of substitution of energy for other factors of production and consumption—by which the methods used in both past and future studies could be characterized, and by which the conclusions of such studies could be compared.[4]

A GENERAL POLICY PLANNING FRAMEWORK

Many energy planning or forecasting studies fail to describe the basic assumptions and models used to produce the study results. The result is that readers of such studies often find it difficult to distinguish between (1) the basic assumptions and methodology of the study and (2) the results found by the study. In cases where such a shortcoming exists, it is impossible to assess whether the results of the study are truly applicable to any real problem. Furthermore, it is not uncommon for there to be no available documented record of the model or of the basic assumptions inherent in the model. A recent example of such a study is President Carter's National Energy Plan,[5] which gives neither documentation of, nor footnote references to, the model used in preparing the Plan. The President's Plan does, however, fortunately provide something else—a sketch of a general policy planning framework, an understanding of which is prerequisite to understanding of the

[3] Energy Demand Studies—An Analysis and Comparison. p. 1–2.

[4] We note that there is no contradiction between economic production and consumption theory, which are parts of the economic subdiscipline of microeconomics, and the laws of thermodynamics (a subdiscipline of physics). Much confusion has arisen from assertions that energy is both totally unique, and completely irreplaceable. Thermodynamic theory, expressed simply, says that energy once used for a given purpose, cannot be used again for the same purpose, but may be used for other less demanding purposes (it does not disappear). A fixed quantity of energy may have a wide and ordered range of qualities (usefulness for various purposes which are either less or more demanding). When economists consider the substitution of other factors of production for energy, they contradict no law of thermodynamics—rather they implicitly recognize qualities or grades or forms of energy which for purposes of economic analysis are not explicitly labeled as energy. Thus, substitution of "capital," or "labor," or "materials" for "energy" in economic analysis is consistent with substitution of lesser quantities of greater quality energy for an alternative of greater quantity and lesser quality.

[5] U.S. Executive Office of the President. Office of Energy Policy and Planning. The National Energy Plan. Washington, U.S. Govt. Print. Off., Apr. 29, 1977. 103 p.

nature of models and their use. The policy planning framework is outlined in the ten principles set forth in Chapter III of the Plan.

It is there stated that the ten principles "provide a framework * * * for present policies * * * also for development of future policies." The following grouping of the ten principles reveals a logical relationship among the principles, and suggests the nature of the implicit model underlying the President's proposals, as well as describing the framework required for rational energy consumption forecasting and planning.

Three of the ten principles, the first, fifth, and eighth, describe the Government's responsibility to be rational and equitable.

> The first principle is that the energy problem can be effectively addressed only by a government that accepts responsibility for dealing with it comprehensively, and by a public that understands its seriousness and is ready to make necessary sacrifices. * * * The fifth principle is that the United States must solve its energy problems in a manner that is equitable tc all regions, sectors, and income groups. * * * The eighth principle is that both energy producers and consumers are entitled to reasonable certainty as to Government policy.

These three principles together articulate the Administration's acceptance of responsibility for dealing with energy problems comprehensively in all respects, and appeal to the public to recognize and approve the Government's acceptance of this responsibility.

THE THEORY OF ECONOMIC POLICY

The work of Jan Tinbergen provides a basis for understanding the role of modeling in economic and energy policy.

Tinbergen received the Noble Prize in Economics for his articulation of the general methodology with which any government must work if it is to deal with economic problems (of which the energy problem is an example) in a comprehensive fashion. The required framework has come to be called the Theory of Economic Policy.[6] The remainder of the President's ten principles of energy policy can be understood in terms of the Theory of Economic Policy, as follows.

The Theory of Economic Policy states that in order to deal with economic problems comprehensively, one must make a list of the economic or economically related goals one wishes to achieve. This the President has done in five other of his principles—the second, third, fourth, ninth, and tenth.

> The second principle is that healthy economic growth must continue. * * * The third principle is that national policies for the protection of the environment must be maintained. * * * The fourth principle is that the United States must reduce its vulnerability to potentially devastating supply interruptions. * * * The ninth principle is that resources in plentiful supply must be used more widely, and that the nation must begin the processes of moderating its use of those in short supply. * * * The tenth principle is that the use of non-conventional sources of energy must be vigorously expanded.

The Theory of Economic Policy states further that in addition to a list of the economic or economically related goals a government wishes to achieve, a list of the means at the Government's disposal (for the achievement of such goals) is required. Finally, a model—explicit or implicit—of the complex interrelationships between the set of goals,

[6] Jan Tinbergen. On The Theory of Economic Policy. Amsterdam, North Holland, 1952. 80 pp.
———. Economic Policy, Principles and Design. Chicago, Rand McNally, 1967. 267 pp.

and the set of means, must be established and used. The President's remaining two principles reflect judgments about the nature of the model which best reflects the realities of the U.S. economy.

> The sixth principle, and the cornerstone of National Energy Policy, is that the growth of energy demand must be restrained through conservation and improved energy efficiency. * * * The seventh principle underlying the National Energy Plan is that energy prices should generally reflect the true replacement cost of energy.

Thus, the President has established his basis for national energy policy—and his judgmental view of the factual or structural relationships between his five goals on one hand, and the few dozen administrative and legislative means he proposes for achieving those goals on the other hand. The President's sixth principle expresses his view that the factual or structural relationship between his five broad goals and his few dozen specific means is one in which substantial reduction in the consumption of energy, relative to continued "healthy economic growth," is possible, The seventh principle expresses the President's view that his goals will be served by policies which raise the effective prices of resources now being used nearer to the cost of the resources which will be needed to replace them. Since the sixth and seventh principles seem to be the only two of the President's principles which appear to reveal views of economic structure, they seem to imply a belief on the President's part that his goals—which are (in addition to healthy economic growth): protecting the environment, reducing energy supply vulnerability, substituting plentiful for scarce energy resources, and expanding the use of non-conventional sources of energy—will all be served by various means of raising the effective prices of the increasingly scarce conventional energy resources.

It is not the purpose of this general discussion of energy forecasting and planning methodology to appraise the President's few dozen specific proposed actions (means for achievement of goals).[7] Neither is it here the purpose to appraise in detail the President's view, or any other view, of economic structure. Rather, the purpose here is to say that a generalized set of goals, and a general apprehension of an appropriate model for energy policy analysis, can be made more specific and quantitative, tested for validity, and finally applied to national policymaking—regardless of what or whose goals and views of economic structure are involved. Further, this can be done by the Congress. The reader is urged to review the following chapters of this document, and to consider how well the studies compared by CRS (and this CRS report itself) adhere to the sound approach outlined in the Theory of Economic Policy, in presenting a portrayal of U.S. energy prospects and possibilities for the future.

The reader is further urged to think about the characteristic of economic structure (or model structure) defined just below (the elasticity of substitution). Is the Theory of Economic Policy a suitable general framework for helping you link your list of goals, through your view of the U.S. economic structure, to the list of means controlled by the Congress, or by your part thereof? Is your view of

---

[7] These means for achievement are summarized in The National Energy Plan, pages xv through xxiii, and are detailed in Chapters IV through VIII of The Plan. The effectiveness of the means in relation to the goals have previously been assessed in documents of the Congressional Research Service, the General Accounting Office, and the Congressional Budget Office.

economic structure encompassed by the concept of elasticity of substitution defined below—and can your view of that economic structure be represented by a low numerical estimate, or by a high or middle-range estimate, of that variable? Finally, could the Theory of Economic Policy as a general framework, together with some elaboration and measurement of the elasticity of substitution as a representation of specific economic structure, enable you to make energy policy decisions more easily?

ELASTICITY OF SUBSTITUTION OF ENERGY FOR OTHER FACTORS

Is Energy Substitutable?—A key point at issue in energy consumption forecasting and planning studies—and in the President's National Energy Plan in particular—is the degree of substitutability of other factors of production (chiefly labor, physical capital and materials) for energy. In certain situations, or over certain time horizons, energy may be either a substitute for and a competitor with labor, or it may be a complementary factor of production—meaning that as more energy is used, more labor is required also. In the latter case only, the limitation of energy may limit employment. Thus, the exact role of energy in the whole economy is complex, and remains to be scientifically resolved. When knowledge of these relationships becomes more certain, then the "relatively undefined and not explicitly stated" models, together with some very explicitly defined but relatively elementary models (see footnote 4) may be replaced by models which are both explicit and theoretically complete.[8]

How Substitutable is Energy?—Hogan and Manne [9] have used the economists' standard textbook definition of the elasticity of substitution [10] to illustrate the range of effects of energy conservation on the level of Gross National Product (GNP). For the purpose of illustration they avoid entanglement in uncertainty as to the correct numerical magnitude of the elasticity of substitution. Instead, they base their computations only on the definition of elasticity of substitution between energy and all other goods, and on the assumption that the elasticity as defined may be assumed constant over a substantial range.[11] They

---

[8] Technically, energy and labor could be found to be substitutes at every point along an "expansion path," and also be found to increase in fairly close proportion as one moves outward along a given expansion path (moves to a larger aggregate GNP). Typically, discussions of positive correlation of both energy consumption and GNP with time, and therefore with each other, use data points taken essentially from a single expansion path. The feasibility of alternative expansion paths as defined in mathematical economics and, more importantly, of transitions from one expansion path to another, has received less attention.

[9] Hogan, William W., and Alan S. Manne. Energy-Economy Interactions: The Fable of the Elephant and the Rabbit? [Energy Modeling Forum Working Paper EMF 1.3, Draft 4], Jan. 12, 1977. 10 p. and mathematical appendix.

[10] Elasticity of substitution is a measure of the effect of a change in the relative prices of production factors A and B on the least-cost proportions of A and B. It is defined as the percentage change in the quantity ratio B/A, divided by the percentage change in the price ratio P_a/P_b. This measure of substitutability under cost-minimizing behavior varies in magnitude from zero to positive (+) infinity, but for practical purposes any magnitude greater than 1.0 may be considered very large.

[11] Such assumptions have a long history of use, as well as a large professional literature addressed to testing their validity. This literature can be regarded as having begun with the early work (1927) of economist and former U.S. Senator Paul Douglas, with Charles Cobb. The early work of Cobb and Douglas was published in 1927 under the title "A Theory of Production." Cobb and Douglas proposed a specific form of mathematical function as an expression of the relationship between and among various inputs to economic production. This function became known as the Cobb-Douglas production function, and is characterized by an elasticity of substitution having the constant value 1.0. Later, a more general form of production function was proposed as a basis for research and testing. This production function assumes that the elasticity of substitution is a constant, but does not assume a numerical figure for that constant. Instead, it leaves the numerical figure to be determined by statistical data taken from the history of actual economic behavior. It is the function last described which forms the basis of the Hogan-Manne paper. This function is known as the Constant-Elasticity-of-Substitution production function (CES production function).

then compute the effects implied by different values for that constant. The "model" they use is therefore not a single model, but a range of "models" of substitution, ranging from no substitutability at all, to infinite substitutability.

They summarize reports of attempts to measure the correct, real world magnitude of the elasticity of substitution, and tell us that the bulk of the evidence urges rejection of both the zero substitutability view and the infinite substitutability view. They then argue that attention should be closely focused on intensive effort to narrow the range of uncertainty in which estimates of the true elasticity of substitution lie, for they find large uncertainties in, but measurable possibilities for, energy substitution. This implies very substantial potential savings of energy consumption with relatively small losses of GNP (other things being constant) or actual increases of GNP with decreased energy consumption, provided other input factors and other policy variables are suitably adjusted, and provided that the correct estimate for the elasticity of substitution turns out to lie in the favorable range.

> Suppose that for reasons of resource conservation, environmental protection or national security, there is a need for reduced energy consumption. Suppose further that there is no reduction [and no increase] in the economic inputs other than energy. * * * What is the resulting impact on GNP? * * * According to this simple model, the long run elasticity can have a startling effect. A 50 percent reduction in energy utilization would produce a 28 percent reduction in GNP if the elasticity is 0.1, but only a 1 percent reduction in GNP if the elasticity is 0.7. * * * Most existing estimates of the price elasticity of demand fall within the range of 0.3 to 0.7. This issue has certainly not been resolved, and there is some evidence for both higher and lower values. It is essential, therefore, that any improved analysis of the energy-economy link provide a careful specification of the elasticity of demand/substitution. Most modeling efforts can be characterized in terms of their treatment of this important concept.[12]

GROSS NATIONAL PRODUCT CHANGES RESULTING FROM ENERGY CONSUMPTION CHANGES FOR DIFFERENT CONSTANT ELASTICITIES

Table 3 and Figure 1 Explained.—The relation of GNP and energy postulated by Hogan and Manne is shown in Table 3 and Figure 1. Note that in Table 3, and in Figure 1 which is plotted from the data of Table 3, there are cases which imply great losses of GNP resulting from reductions in energy consumption, and cases which imply very small losses of GNP resulting from reductions in energy consumption. The difference between the pessimistic cases and the optimistic cases arises wholly from the true numerical magnitude of the elasticity of substitution, which ranges in principle from zero to positive (+) infinity, but which is shown numerically and plotted for the values 0.7, 0.5, 0.3, 0.2, and 0.1. In essence, this table and figure show what would be expected for various assumptions of elasticity.

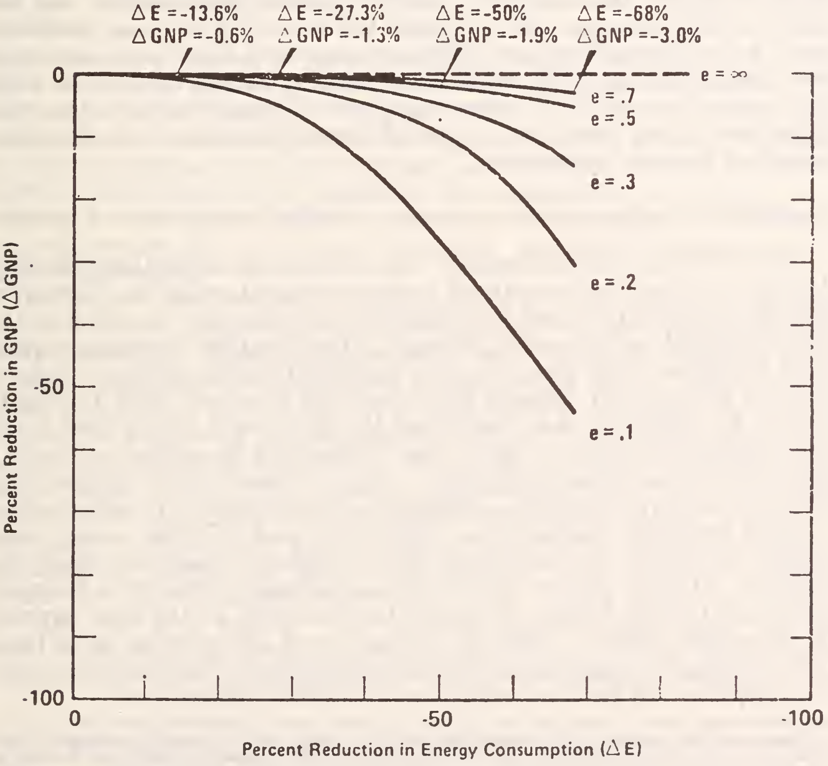
The arrangement of data in Table 3, and the arrangement of axes in Figure 1, are chosen to complement each other. The most pessimistic case, elasticity (e)=0.1 in the bottom row of Table 3, emphasizes the rapidly sinking GNP which arises from increased energy savings at such a small elasticity. (The percent change in GNP is written ΔGNP or "delta GNP," and the percent change in energy consumption is written ΔE or "delta E.") The sinking GNP for this case is illustrated

[12] Hogan and Manne, op. cit., p. 4–5.

Table 3. GROSS NATIONAL PRODUCT CHANGES RESULTING FROM ENERGY CONSUMPTION CHANGES FOR DIFFERENT CONSTANT ELASTICITIES

	Percent Reduction in Energy Consumption				
	0	13.6	27.3	50.0	68.0
Elasticity of Demand/ Substitution (e)	Percent Reduction in GNP				
0.7	0	0.1	0.3	1.2	3.0
0.5	0	0.1	0.4	1.9	5.2
0.3	0	0.2	0.8	4.3	14.3
0.2	0	0.3	1.3	9.2	30.8
0.1	0	0.6	4.5	27.7	53.8

Figure 1. GROSS NATIONAL PRODUCT CHANGES RESULTING FROM ENERGY CONSUMPTION CHANGES FOR DIFFERENT CONSTANT ELASTICITIES



Note: All data from Hogan and Manne, op. cit., p. 10.

graphically in Figure 1 by the curve for e=0.1, which drops precipitously from $\Delta GNP=0$ for $\Delta E=0$, to $\Delta GNP=-53.8$ percent for $\Delta E=-68$ percent. However for the most optimistic case, the curve for which e=0.7, the GNP is hardly affected—dropping only from $\Delta GNP=0$ for $\Delta E=0$, to $\Delta GNP=-3.0$ percent for $\Delta E=-68$ percent. Each of the four points marked by darts in Figure 1 is on a different curve, the first on e=0.1, and the fourth on e=0.7.

The lower axis of Figure 1, the Percent Reduction in Energy Consumption (ΔE), is chosen to suggest implicitly a passage of time from left to right, as well as a greater saving of energy consumption. One may interpret the smaller and more pessimistic values of e, therefore, as short-run elasticities (about one year) and the larger and more optimistic values of e as long-run elasticities (30–40 years or more). Thus, Figure 1 suggests that in a short run for which e=0.1, energy savings could be as great as 13.6 percent with a GNP loss of only 0.6 percent. In a very long run in which the entire U.S. capital stock might be replaced, the energy consumption could be reduced by as much as 68 percent with a GNP loss of only 3.0 percent, if the long-run elasticity (e) turned out in reality to be the very optimistic figure of 0.7. In any case, having the best possible estimates of the true elasticity (e) for different time horizons appears to be crucial, because for horizons less than a year, e might be even less than 0.1, and for horizons of 50 years or more, e might fall short of 0.7. If, on the other hand, e for a horizon of, say, 20 years proved to be as large as e=0.3, then energy savings (ΔE) could be as large as 27.3 percent with only a 0.8 percent loss of GNP, other input factors being constant. Accurate estimates of the elasticity (e) for different time horizons therefore appear to be very important.

ELASTICITY IN THE WHOLE ECONOMY VERSUS ELASTICITY IN DETAIL

The President's sixth principle, "the cornerstone of National Energy Policy," is that the growth of energy demand must be restrained through conservation and improved energy efficiency. In view of the goal embodied in the second principle, "that healthy economic growth must continue," it is clear that the President and his advisors believe that the elasticity of demand for energy [13] is relatively high. Certainly it must be higher in their view than the figure of 0.1 upon which the most pessimistic curve is based, but it need not be as high as the 0.7 upon which the most optimistic curve is based. Since Hogan and Manne summarize available estimates of the elasticity of substitution as lying probably between the figures 0.3 and 0.7, the reader may choose to ignore the case favored by diehard pessimists that the elasticity of substitution is 0.0 (no substitution whatever between energy and other factors of production) as well as the case favored by incurable optimists that the elasticity of substitution is so large (1.0 or greater) that practically any reduction in the level of energy consumption can be accommodated with trivial discomfort.

[13] Hogan and Manne observe that for the aggregate U.S. economy the elasticity of substitution of other factors of production and consumption for energy is essentially the same as the elasticity of demand for energy, since all of the possible substitutions for energy are encompassed in "other factors."

A two-part problem for energy policy analysts, and elected officials alike, is (1) to determine to a fair approximation the true elasticity of substitution in the U.S. economy as a whole or in its separate parts, and (2) to identify a single set of policy measures (there may be several such sets) which will cause the desired reductions of energy use and increases in the use of other factors (including labor) to be accomplished. In principle, this involves considering a bill which includes in its list of available policy actions all of the policy actions considered potentially relevant, and in its list of goals all of the economic, environmental, social, and political goals which are thought potentially to be affected by any of the considered means. This legislative process need not be entirely different from the process of building a "model" which would encompass all of these considerations.[14]

WHAT ARE THE MEANS THROUGH WHICH FEASIBLE SUBSTITUTION MAY BE EFFECTED?

Tinbergen's Theory of Economic Policy tells us that for any number of separate goals, there must be an equal (or greater) number of separate means for achievement of goals.[15] Thus, if it is desired (1) to increase total employment of labor while (2) simultaneously reducing the per capita consumption of energy, at least two distinct policy variables must be adjusted. For example, one might have to (1) increase taxes on the consumption of energy, thereby raising its effective price to the user, while (2) simultaneously arranging to maintain the level of national income, or the growth rate thereof, by restoring private sector purchasing power through reductions of taxes imposed on other consumer or producer goods and services. Among the alternatives which have been suggested (for restoration of private purchasing power) are reduction of taxes on the employment of labor, and tax credits for investment in energy production capital or resource exploration.

If there are only two goals desired, and more than two available and effective means, there may be more than one feasible combination of means which can accomplish the stated set of goals. Having an excess of means implies that additional goals (needs) might be identified and accomplished in the future, as desired. For example, the President's five ambitious and separate goals listed earlier will of course require the coordinated exercise of at least five powerful and independent means. Since the President proposed not just five, but several dozen specific legislative and administrative actions, careful consideration may be required to see if the five broad goals implicitly contain unidentified component goals, and whether each of the few dozen means are indeed independent of each other. If the means to be used are still of greater number than the listed goals, one may ask whether the President holds unstated goals in addition to those stated, and whether there are additional goals which are unstated because they

---

[14] For a professional economist-engineer's view of a starting point for a model encompassing all of these considerations see: William W. Hogan. Capital-Energy Complementarity in Aggregate Energy-Economic Analysis. Energy Modeling Forum [working paper]. (Stanford) Institute for Energy Studies. August 1977. 27 p.

[15] In the dynamic corollary to Tinbergen's Theory of Economic Policy—the Theory of Optimal Control—a similar principle applies.

are not held and not identified, which could be identified and accomplished with the means at hand.[16]

FORECASTING AND PLANNING METHODS AND THE LEGISLATIVE PROCESS

Scientific results, such as a reliable estimate of the elasticity of substitution for energy, computed from good statistical and engineering data, can be a help in molding and passing a bill representing a congressional "model" of energy use. In considering individual portions of such a bill, some amendments will be proposed which, in effect, require a vote by a subcommittee, committee, chamber, or committee of conference, on a particular aspect of national or interregional economic structure. In a vote on such an amendment, Congress or one of its parts may be regarded in effect as rendering a judgment as to whether the weight of evidence gained from science and/or from personal experience favors one or another view of how a portion of the economic world operates.[17]

While some aspects of economic structure are constants of physical or behavioral science, there are additional aspects of economic structure which are determined as a direct result of congressional legislation. Professional model builders recognize this kind of structural constant with the term "statutory coefficient," of which particularly clear examples are numerical percentage tax rates.

In many cases, however, votes in Congress and in its parts are not neatly divided into (1) rendering judgment as to the weight of evidence favoring a particular estimate of scientific law, and (2) laying down statutory coefficients which themselves become part of our economic structure. Often the amendments offered are less clear-cut and more ambiguous, combining both judgment of scientific law, and creating statutory economic structure (and in addition affecting the flow of Federal expenditures).

It may be helpful, however, occasionally to view the Congress as a model builder which (in effect) makes its own estimate of economic structure as embodied in scientific law, and specifies additional economic structure by creating statutory coefficients such as tax tables.

---

[16] Peer review elicited the comment that—whereas the Theory of Economic Policy states that the number of means must be at least equal to the number of goals—in legislative politics a vote may be cast not from a single motive but from a combination of motives. This allows the legislator to accomplish several political "goals" with the means of a single vote. The argument was made that the Theory of Economic Policy is rendered impotent or inapplicable by presentation of this example which seems to contradict it, and thus disproves its generality. The comment confuses the definitions of both means and goals. Specifically, the comment does not recognize that goals are quantitative in nature, not just qualitative. Similarly, the manipulation of means involves quantitative, not just qualitative adjustments. A goal in economics is not just any change in a given direction of an economic variable. Rather a goal is attainment of a specific numerical target value (or milestone) for that variable. Similarly, it is not just in politics, but also in the mathematical world of economic models, that a numerical change in a single means (or policy variable) may effect numerical changes in more than one goal (or target variable). In fact, a numerical change in a single policy variable will almost always effect changes in multiple target variables. The point that the peer review comment misses is that such multiple changes are not independent of each other when a single policy variable is used. If an adjustment in a single means or policy variable causes one goal to be fulfilled 100%, and a second goal to be overfulfilled to the extent of 150% of the goal, a second means must be identified and manipulated so that the action of the two means in concert results in fulfillment of the first goal 100% with simultaneous fulfillment of the second goal 100%, instead of the second target or goal being missed by +50 percent.

[17] Peer review elicited the comment that the above paragraph expressed a naive and idealistic view of how the Congress functions. To wit: votes in Congress may be affected by many more factors than by personal views, however derived, of how the economic world operates. Among such additional determinants may be parochial views of the interests of a particular State, congressional district, industry, or other constituent group. Notwithstanding this peer-review comment, we believe such discussion irrelevant here. This chapter is not intended to be an academic political science treatise on how the Congress functions. This chapter is written for Members of Congress, not for graduate students in legislative affairs. As such, the information presented is intended to represent an accurate expression of what science has to offer legislators involved in national decisions. It is not the role of this report to instruct Members of Congress in the process of the Congress. However, scientific information (as one of the information inputs entering that process) is one of the sources of authority which individual legislators may choose to use for legislative advantage.

To the extent that Congress institutionalizes, in its own staff analytical apparatus, the results of its own economic engineering,[18] it is in a stronger position to accept, modify, or reject the Executive's belief that a particular new policy modification—working through the economic structure that Congress has in part apprehended from science, and in part created through statutory law—will accomplish particular goals.

A professional modeling technique—a methodology of forecasting and planning—which could be helpful to the Congress in evaluating Executive-proposed spending and taxing scenarios, is that of making conditional forecasts. That is, arranging to compute on progressively shorter schedules (in the ideal case just before relevant votes are taken) alternative paths, over several decades, of important variables such as income and employment by region or State, conditional upon the result of the vote to be taken. Neither a single path forecast (point forecasts for each of several future years) nor multiple energy production and consumption capacities assembled into a complex array of energy balances (with supposed surpluses or shortages) will quite fit this problem.

History suggests that new technologies may arise which will increase the alternatives available to Congress and the Nation. When this happens, the multiple paths computed based on earlier available technologies may be rendered obsolete by new, more desirable paths (perhaps based on an extended range of feasible elasticities). But there is hardly any substitute for the best possible knowledge of the paths available based on the technologies available now. A problem for Congress may be, acting in response to all of the usual influences and all of the available scientific information, to legislate a program of sufficient breadth, sufficiently well-coordinated, to forestall future energy problems. In considering substantive actions of current energy and economic policy, and substantive actions to fund research and development on energy production technology and hardware, the Congress may simultaneously appraise whether its computational tools and institutional arrangements for using such tools (as well as the degree of comprehensiveness of its research programs in basic and applied economic science) are fully capable of exploiting the possibilities of an internally-consistent approach to policymaking such as outlined in the Theory of Economic Policy.

---

[18] The process by which congressional estimates of physical or behavioral constants of economic structure (and congressional specification of statutory economic structure) might become plugged into Congress' computer(s) is left unelaborated here.

The Demand for Energy—an Overview and Summary of Six Studies

(By Howard Useem*)

OVERVIEW

Since 1955 domestic energy consumption has been increasing at a 3.0 percent annual rate on average, while domestic energy production has been expanding at a 2.2 percent annual rate. This small, but significant, gap between the growth of domestic energy consumption and production has led the United States from a position of energy self-sufficiency in the late 1950's to its current position of heavy dependence on foreign energy supplies. In 1975 the United States relied on foreign sources for one-sixth of its total energy needs, and for nearly 40 percent of its petroleum supply.

Between 1955 and 1975 U.S. net energy consumption rose from 35.0 quadrillion Btu's (called "quads") to 57.5 quads, a 64 percent increase. While every sector has exhibited a significant growth in energy consumption (see Table I below), energy consumption by the transportation sector has grown the most—about 8.7 quads. This is an annual growth rate of more than 3.2 percent.

However, in recent years it appears that increasing energy prices have led to some moderation in the growth of energy consumption and, in some cases, a net decline in energy consumption. In the case of the industrial sector, net energy consumption has fallen almost continuously from a peak of 24.0 quads in 1973 to 21.6 quads in 1975.

TABLE 4.—TOTAL U.S. NET ENERGY CONSUMPTION BY CONSUMING SECTORS

[Quadrillion Btu's]

Year	Household and commercial	Industrial	Transportation
1955	9.5	15.0	9.8
1960	11.4	15.9	10.8
1965	13.8	18.8	12.7
1970	17.0	22.4	16.5
1975	17.3	21.6	18.5

Source: American Petroleum Institute. Basic Petroleum Data Book. Cites various Department of the Interior publications as sources.

SUMMARIES OF SIX STUDIES OF ENERGY DEMAND [1]

The following is an overview and individual summaries of six recent studies of energy demand. The six studies reviewed are: "The Demand for Energy in the United States," by Alvin Kaufman, Warren Farb,

*Howard Useem is an economic analyst at the Congressional Research Service.

[1] Most econometric models assume that price will adjust such that supply equals demand, and demand will equal consumption: in other words, the market "clears." If a model does not provide for price adjustments then markets will not necessarily "clear" and it would then be possible for consumption not to be equal to demand.

and Barbara Daly, Congressional Research Service, The Library of Congress (April 21, 1977); Energy Review: "Energy Outlook," by Alvin Cook, Data Resources Incorporated (1977); "Energy Outlook 1977–1990," by Exxon Company U.S.A. (January 1977); "National Energy Outlook," by the Federal Energy Administration (February 1976); "Energy Demand Studies: Major Consuming Countries," by Paul Basil (ed), Caroll Wilson (project director), et al., Workshop on Alternative Energy Strategies (1976); and "United States Energy Through the Year 2000" (Revised), by Walter Dupree and John S. Carsentino, Bureau of Mines, U.S. Department of the Interior (1975).

Despite the different assumptions and methodologies used in these various energy demand studies, their conclusions with respect to future energy demand are surprisingly similar. The energy demand projections for the year 1980 range from 80.2 quads to 87.1 quads; if the highest and lowest projections are discarded then the array of projections closes to 81.3 quads to 85.4 quads, a 4.1 quad (5 percent) range.

For 1985 there is slightly more divergence in the demand projections. Discarding the highest and lowest projections, the demand projections for 1985 range from 91.2 quads to 103.5 quads, a 12.3 quad (13.5 percent) difference. It should be noted that these projections are not significantly different from those contained in the President's National Energy Plan, which forecasts energy demand in 1985 without conservation measures to be 102.3 quads, and 98.3 quads with the conservation measures contained in the plan.

In 1990 the difference between the various projections narrow. Again disregarding the highest and lowest projections, the remaining forecasts of energy demand for 1990 range from 104.5 quads to 116.1 quads, a 11.6 quad (11.1 percent) difference.

Four of the six demand studies contain alternative scenarios based on alternate assumptions. Three of these four studies find industrial energy demand relatively unaffected by changes in energy prices and energy policy. In the CRS study, "Demand for Energy in the United States, 1976–1990," the difference between industrial energy demand in 1985 between the optimistic and pessimistic cases is only 2.3 quads. In the four alternative cases forecast in "Energy Review: Energy Outlook," by D.R.I., industrial demand in 1985 ranges from 57.8 quads to 60.1 quads. Similarly, in the reference case scenario contained in the Federal Energy Administration's "National Energy Outlook," industrial energy demand in 1990 ranges from 74.1 to 74.3 quads despite significantly different assumptions concerning world oil prices. Only the WAES study, "Energy Demand Studies: Major Consuming Countries," projects a significant change in industrial energy demand (7.7 quads) given different assumptions.

These same four studies find that different assumptions concerning energy policy and prices lead to a moderate to significant impact on household/commercial energy consumption. At the low end of the range, the D.R.I. study finds that alternative energy policies can change household/commercial demand by only 7 percent (1.1 quads) in 1985. At the other end of the range, the WAES study finds that household/commercial energy demand can be altered by as much as 41 percent (6.1 quads) in 1985.

21-616—78——3

The findings on transportation energy demand are mixed. At the low end of the scale, the D.R.I. and CRS studies find that transportation energy demand can be altered in 1985 by at most 2 percent (.5 quads). At the high end the WAES study finds that transportation energy demand can be affected in 1985 by as much as 20 percent (3.5 quads).

The following are individual summaries of the energy demand forecasts contained in the six studies previously cited and discussed. At the end of the summaries there is an overall summary table.

THE DEMAND FOR ENERGY IN THE UNITED STATES, 1976–1990

Author, date: Kaufman, Alvin, Warren Farb and Barbara Daly. Congressional Research Service, The Library of Congress. April 21, 1977.

Range of study: 1976 through 1990.

Methodology

Using the Data Resource Inc. (DRI) long-term macroeconomic model of the U.S. economy and the DRI energy model, CRS produced three energy demand forecasts: an optimistic case, a pessimistic case, and a reference case. The reference case was an average of the optimistic and pessimistic cases and therefore will not be discussed.

Assumptions

The optimistic case assumes relatively steady U.S. economic growth through 1990. Real GNP grows at a 3.5 percent annual rate from 1976 through 1990. Inflation, as measured by the implicit price deflator, averages 4.3 percent, and unemployment averages 5.4 percent. The forecast assumes decontrol of new gas prices (but old gas will continue under controls), early availability of natural gas from Alaska, and generally increasing energy prices. Crude oil is assumed to increase from $10.60 per barrel in 1976 to $13.30 in 1990 in real terms. Natural gas prices are assumed to increase more sharply, with average real industrial prices increasing from 10.8 cents per therm in 1976 to 18.3 cents in 1990. The delivered real price of coal is assumed to go from about $17 per ton to $19.40 per ton by 1990. However, electricity, in real terms, is assumed to decline from 3.6 cents per kilowatt hour to 3.3 cents.

The pessimistic case assumes that the economy will experience periodic recessions throughout the forecast period and that real GNP will grow at an annual rate of 3.4 percent. Inflation is expected to average 5.1 percent, and unemployment 5.7 percent throughout the forecast period. The pessimistic forecast assumes that total energy demand will be lower than under the optimistic forecast, but energy prices will be higher. The crucial energy assumptions in this forecast are a decontrol of crude oil prices by 1979, decontrol of new natural gas prices at the end of 1977, and the cessation of new nuclear construction after 1985. By 1990, in real terms, the price of energy is expected to be: $18 per barrel for petroleum, $.26 per therm of natural gas, and $19.40 per ton of coal.

Findings

In the optimistic case, net energy demand rises from 59.3 quads in 1976, to 83.5 quads in 1990, a compound annual growth rate of 2.5

percent. Household and commercial demand grows during this period by only 1.6 percent per year, while industrial demand will grow by 4.1 percent. During the 1976–1990 period energy use by the transportation sector is projected to grow by only 3.4 quads—a compound annual growth rate of only 1.2 percent. Energy conversion losses, stemming mainly from the generation of electricity, are anticipated to rise from 14.7 quads in 1976, to 29.9 quads in 1990.

In the pessimistic case, net energy demand is expected to rise from 59.3 quads in 1976 to 75.5 quads in 1990—a compound annual growth rate of 1.4 percent. Household and commercial demand is expected to grow at an annual rate of 1.4 percent, industrial demand by 2 percent, and transportation energy demand by 0.6 percent. In this forecast total demand for electricity is expected to remain relatively stable as compared with the optimistic forecast.

ENERGY REVIEW: ENERGY OUTLOOK

Author, date: Cook, Alvin. Data Resources Incorporated. 1977.
Range of study: 1977 through 1990.

Methodology

Using the DRI macroeconomic models of the U.S. economy and the energy sector, the study makes a range of forecasts based on different assumptions.

Assumptions

The control case is the base case for comparison, and assumes that past Federal energy policy will not be altered. Crude oil price controls are assumed to continue through 1979. Through 1980 the composite price of old and new oil is assumed to increase at a 10 percent annual rate. Thereafter, new oil will increase at a 10 percent annual rate and old oil at a 15 percent rate until they both reach the level of world oil prices in 1986. Thereafter, both domestic and foreign oil is assumed to increase in price by 7.5 percent per year.

In 1980 new natural gas in the interstate market from onshore sources is assumed to be deregulated, and in 1985 deregulation is extended to new gas from offshore sources. Due to deregulation, gas gas production in 1980 is assumed to be 17.9 trillion cubic feet and oil production 9.4 million barrels per day. The price of coal rises by $.50 per ton as a result of labor unrest in the coal industry and additional land reclamation costs.

In the Carter case forecast, it is assumed the President Carter's energy proposals are accepted by Congress. As a result of the taxes on crude oil, refiner acquisition costs increases at a rate of 14 to 17 percent per year from 1978 through 1980, and a 6.5 percent rate thereafter. Natural gas prices will increase 9 percent per year through 1980, and 10 percent per year thereafter. Industrial natural gas prices are assumed to increase by 21 percent per year through 1980, 12.5 percent per year from 1980 to 1985, and 6.5 percent thereafter. Electrical prices are expected to increase by only 5 percent per year through 1980.

The pessimistic case assumes that the price of domestic petroleum will increase at the same rate as in the control case, but that OPEC petroleum prices will increase at 10 percent per year. At the same time,

tight controls on domestic natural gas prices will keep domestic production depressed and force industrial users to turn to high priced imported gas. Furthermore, it is assumed that there will be less capacity in the coal industry than in the control case.

The optimistic case assumes that OPEC will increase crude oil prices at the same rate as domestic price increases assumed in the control case, but that domestic crude oil price regulations will be eliminated. It is assumed that decontrol of new natural gas will create additional domestic supplies of natural gas. This case also assumes that there will be more capacity for producing strip mined coal than in the control case.

Findings

In the control case total consumption of energy increases from 73.0 quads in 1976 to 110.9 quads in 1990. From 1975 through 1980, the overall average annual increase in energy demand is 4.2 percent; from 1976 through 1990 the average annual increase is 3.0 percent. Household and commercial demand increases from 14.7 quads in 1976 to 18.4 quads in 1990—an annual growth rate of 1.6 percent. Industrial demand for energy grows at a 4.2 percent annual rate from 39.6 quads in 1976 to 70.8 quads in 1990.

As compared to the control case, the Carter case reduces the growth in energy demand by less than .3 percentage points. Household/commercial energy demand is 1.7 quads lower in 1990 in the Carter case than it would have been in the control case, and industrial demand is 3 quads less; transportation demand for energy is projected to rise slightly under the Carter case.

Similarly, the assumptions of the pessimistic and optimistic cases lead to a moderation of overall energy demand, reducing demand in 1990 as compared to the control case by 6.9 quads and 3.3 quads, respectively. Most of these savings come from the industrial sector whose demand in 1990 in the pessimistic case is 5.6 quads lower than in the control case and 2.3 quads lower in the optimistic case.

ENERGY OUTLOOK 1977–1990

Author, date: Exxon Company, U.S.A. January 1977.
Range of study: 1977 through 1990.

Methodology

Although the report provides no indication of the methodology Exxon used in making its forecasts, it appears that they derived their projections from econometric models.

Assumptions

The forecast assumes that policies relating to energy consumption are consistent with the need for national economic growth. Outer Continental Shelf oil and gas acreage as well as Federal oil shale and coal acreage will be leased in a timely manner. There will be a realistic balance between energy, economic, and environmental goals. Federal policies will not reduce or restrict the petroleum industry's ability to raise capital funds and air quality standards will be delayed temporarily in order to permit greater use of coal.

Between 1977 and 1990, it is assumed that the economy will continue to grow toward full employment. GNP will grow at an annual average rate of 3.5 percent which is slightly lower than the 4 percent growth rate over the 1960–73 period.

Energy prices are assumed to increase at the maximum allowable rate under the Energy Policy and Conservation Act of 1975 and the Energy Conservation and Production Act of 1976. After the 1980 expiration of the price control authority contained in these acts, energy prices are then assumed to grow at about the rate of inflation.

Findings

Total energy demand is projected to increase from 76.4 quads in 1977, to 109.9 quads in 1990—an annual growth rate of about 2.8 percent per year.

Due to rapid improvements in energy-use efficiency and slower economic growth, the growth of energy demand by the industrial sector is expected to decline sharply from historic rates. Energy demand is expected to increase from 31.0 quads in 1977 to 44.8 quads in 1990—an annual average growth rate of 2.9 percent. Due primarily to increased mileage efficiency of new automobiles, transportation energy demand growth will also drop significantly below historic rates. Transportation energy demand will increase from 19.6 quads in 1977, to 24.7 quads in 1990—an annual average rate of growth of 1.8 percent.

Similarly, the residential and commercial demand for energy will grow at less than the historic rate. Demand will increase at 3.5 percent annual rate from 25.8 quads in 1977, to 40.4 quads in 1990.

THE NATIONAL ENERGY OUTLOOK

Author, date: Federal Energy Administration. February 1976.
Range of study: 1976 through 1990.

Methodology

The F.E.A. forecast is based on projections made by its macroeconomic model of the U.S. energy system, the Project Independence Evaluation System (PIES). According to the National Energy Outlook (NEO), PIES is a model of the technologies, leadtimes, costs, and geographical locations which affect energy supplies from the point of discovery, through production, transportation, conversion to useable form, and final consumption demand by the various sectors of the economy. Although the NEO makes ten different projections based on ten different scenarios (e.g., reference case; conservation case; acceleration case; $7.50 regulation case; $9 regulation case, etc.) only projections for the base case, the "reference case," will be discussed. This case makes three different demand forecasts by assuming three different prices for world oil, $8 per barrel, $13 per barrel, and $16 per barrel.

Assumptions

The PIES model projections are made within the framework of a Data Resources Inc. (DRI) macroeconomic model of the U.S. economy. This model expects GNP to grow at a 5.5 percent annual rate during earlier years of the projections, and then to fall to less than

3 percent during the latter years. Personal income is assumed to grow by 4.3 percent during the 1975–1980 period, but is expected to decline to a 2.8 percent growth rate in the 1985–1990 period. The population is expected to grow at about 1 percent per year. During the 1975–1990 period inflation, as measured by the consumer price index, is expected to decline from 5.2 percent per year to 3.9 percent. In the reference case, fuel prices for the residential, commercial, and industrial sectors are projected to increase an average by 1.5 percent per year from 1974 through 1985. Coal prices are expected to increase an average of 2.2 percent per year, oil prices by 0.7 percent per year, natural gas prices by 6.2 percent per year, and electricity prices by 2.1 percent per year. For electric utility sector, fuel prices are projected to grow at an annual average rate of 2.1 percent between 1974 and 1985.

Findings

In the $13 reference case, energy demand is projected to increase from 73.1 quads in 1974 to 116.1 quads in 1990. This is a 2.9 percent growth rate, as compared to the historical rate of 3.6 percent. During this period, household/commercial demand grows by about 1.1 percent per year, industrial electrical demand by 3.8 percent per year, and transportation demand by 2.0 percent per year.

In the $8 reference case, total energy demand increases by 3.2 percent per year, and in the $16 reference case demand increases by 2.8 percent per year. Higher oil prices mainly affect household/commercial energy demand, reducing it from a 1.9 percent per year growth rate (1974–1990) in the $8 reference case, to 0.7 percent in the $16 reference case. Similarly, energy demand in the transportation sector drops from a 2.8 percent annual increase in the $8 reference case to a 1.7 percent annual increase in the $16 reference case. However, in the industrial sector rising prices have little effect on reducing energy demand which reaches in all three cases 74 quads in 1990.

ENERGY DEMAND STUDIES: MAJOR CONSUMING COUNTRIES

Author, date: Basile, Paul (ed.) and Carroll L. Wilson (project director). Workshop on Alternative Energy Strategies (WAES). 1977.

Range of study: 1972 through 1985.

Methodology

The WAES study uses the Wharton Annual and Industry Forecasting macroeconomic model of the U.S. economy to make its projections concerning energy demand. Six forecasts are made (A, B, C, C′, D, and E) using various assumptions about Federal energy policy, oil prices, and economic growth, Since cases B and E represent the low and high extremum in the range of energe demand forecasts, only these two cases will be summarized.

Assumptions

Case B assumes a slow rate of economic growth coupled with rising oil prices and a vigorous national energy policy to conserve energy. GNP is assumed to grow by an average of 3.2 percent per year over the 1976–1985 period. During the 1977–1979 period, it is assumed that the Federal Reserve Board would pursue a very tight monetary policy,

and a moderately tight policy thereafter. World trade is assumed to decline during this period. The world price of oil is assumed to increase to $17.50 per barrel (in real terms) by 1985.

Case E assumes high economic growth coupled with falling oil prices and restrained national energy conservation policies. GNP is assumed to grow at an annual rate of 4.4 percent in the 1976–1985 period. The scenario assumes that world trade will increase during the 1976–1985 period, that there will be a $10 billion tax cut in 1982, and a $20 billion tax cut in 1983. The world price of crude oil is assumed to fall to $7.66 a barrel by 1985.

Findings

In Case B total energy demand is forecasted to rise from 71.6 quads in 1972 to 80.7 quads by 1985—an annual growth rate of less than 1 percent. Rising energy prices induce consumers to shift from automobiles to public transportation, causing automobile energy usage to drop by 1.1 quads and public transportation energy usage to increase by 0.6 quads. Energy demand in the household/commerical sector is forecasted to decrease by 0.9 quads, caused mainly by significant reductions in fossil fuel space heating and air conditioning. However, industrial energy demand is forecasted to increase at the same time from 20.5 quads to 26.8 quads—an annual growth rate of 2.1 percent.

In Case E total energy demand is forecasted to rise from 71.6 quads in 1972 to 106.9 quads in 1985—an annual growth rate of 3.1 percent. Demand in the household and commercial sector grows from 15.6 quads to 20.8 quads mainly as a result of increased use of fossil fuels for space heating and air conditioning. Industrial demand grows by 4.1 percent per year from 20.5 quasd to 34.5 quads. Transportation demand is forecasted to grow by only 1.7 percent per year, from 17.0 quads in 1972 to 21.2 quads in 1985. Most of this growth comes as a result of increased air travel, and increased use of freight. Automobile energy demand is projected to grow by only 0.1 percent per year, for a total increase of .17 quads.

UNITED STATES ENERGY THROUGH THE YEAR 2000 (REVISED)

Author, date: Dupree, Walter G. and John S. Corsentino. Bureau of Mines, U.S. Department of the Interior. December 1975.

Range of study: 1974 through 2000.

Methodology

The report gives little indication of the methodology used but states that the projections are based on historical trends where such trends were found by the authors to be significant and consistent. However, the report stresses that while the projections are made using a variety of forecasting techniques, they are essentially judgmental and rely upon the "personal judgments of energy specialists in the Bureau of Mines." (Report, p. 26)

Assumptions

Between 1974 and 2000, the report assumes that GNP will grow in real terms at an average compound rate of 3.3 percent per year. During the same period, the population is projected to grow by an average compound rate of 0.8 percent per year.

In terms of Federal energy policies, the report assumes that: (1) strip mining will not be so restrictive that it precludes surface mining of coal; (2) leasing of Outer Continental Shelf (OCS) lands would continue at an accelerated pace; (3) Federal coal, oil shale, and geothermal lands would continue to be leased; (4) there would be continued Federal support of energy research and development; (5) the Federal Power Commission would allow natural gas prices to rise fairly rapidly; (6) domestic crude oil price controls would be eliminated; and (7) moves would be made to rationalize the world petroleum market.

Findings

The report concludes that total gross energy inputs into the economy will rise from 73.1 quads in 1974 to 163.4 quads in 2000—a compound average annual growth rate of 3.2 percent. Net energy use is projected to rise from 59.9 quads in 1974 to 110.2 quads in 2000—a compound average annual growth rate of 2.4 percent. The rising difference between gross and net energy inputs will stem mainly from energy conversion losses which increase from 18.1 percent of total energy use in 1974 to 32.5 percent in 2000. Most of these losses will occur as a consequence of increased electrification which has high conversion losses.

Assuming a 3.3 percent growth rate in real GNP, the energy to GNP ratio will fall from 89,000 Btu per dollar in 1974 to a little under 78,000 Btu per dollar in 2000. Given the 0.8 percent growth rate in population, the energy consumption per capita will rise dramatically from 345 million Btu per person in 1974 to 619 million Btu per person in 2000.

During the 1974 to 2000 period, household and commercial consumption of energy will rise by 98 percent, industrial consumption will rise by 80 percent and transportation uses will rise by 76 percent—annual compound growth rates of 2.7 percent, 2.3 percent, and 2.2 percent, respectively.

TABLE 5.—SUMMARY TABLE OF 6 ENERGY DEMAND FORECASTS

	In quadrillion Btu										
			Sectoral energy use								
	Gross energy use	Net energy use	Household and commercial	Indus-trial	Trans-portation	Population (million)	Gross national product (million dollar)	Energy/GNP ratio (thousand Btu per dollar)	Energy/capita ratio (million Btu per person)	Unemploy-ment rate (percent)	Inflation rate (percent)
Demand for energy in the United States, 1976-90, CRS-1977:							Average annual growth rate				As measured by the implicit price deflator
Optimistic case:											
1976	74.0	59.3	18.8	21.1	19.3	[1] NI	*8.1%	NI	NI		
1980	85.2	65.7	17.5	27.7	20.5	NI	(*current $)	NI	NI	5.4	4.3
1985	98.4	74.1	20.2	32.2	21.7	NI	**3.5%	NI	NI	average	
1990	113.4	83.5	23.5	37.3	22.7	NI	(**constant $)	NI	NI		
Pessimistic case:											
1976	74.0	59.3	18.8	21.2	19.3	NI	*8.7%	NI	NI		
1980	81.3	62.1	15.0	26.7	20.4	NI	(current $)	NI	NI	5.7	5.1
1985	91.2	67.0	15.9	29.9	21.2	NI	**3.4%	NI	NI	average	
1990	104.5	75.5	18.1	35.2	22.2	NI	(**constant $)	NI	NI		
Energy review: Energy outlook (DRI, 1977):							Average annual growth rate of real GNP				Average annual rate of change as measured by the Consumer Price Index
Control case:			*Includes electrical generation								
1976	73.0	NI	14.7	39.6	18.7	NI		NI	NI	NI	1976 5.7
1980	85.4	NI	15.8	49.2	20.4	NI	1975-80 5.0%	NI	NI	NI	1980 5.4
1985	97.9	NI	16.8	60.1	21.0	NI	1980-85 3.5%	NI	NI	NI	1985 5.4
1990	110.9	NI	18.4	70.8	21.7	NI	1985-90 3.0%	NI	NI	NI	1990 4.0
Carter case:											
1976	73.0	NI	14.7	39.6	18.7	NI		NI	NI	NI	1976 5.7
1980	83.3	NI	15.4	48.2	20.2	NI	1975-80 5.0%	NI	NI	NI	1980 6.5
1985	94.7	NI	15.7	57.9	21.0	NI	1980-85 3.5%	NI	NI	NI	1985 4.8
1990	106.5	NI	16.7	67.8	21.9	NI	1985-90 3.0%	NI	NI	NI	1990 4.3
Pessimistic case:											
1976	73.0	NI	14.7	39.6	18.7	NI		NI	NI	NI	1976 5.7
1980	84.4	NI	15.3	48.9	20.2	NI	1975-80 5.3%	NI	NI	NI	1980 5.9
1985	94.3	NI	16.0	57.8	20.5	NI	1980-85 2.5%	NI	NI	NI	1985 5.9
1990	104.0	NI	17.9	65.2	20.9	NI	1985-90 2.0%	NI	NI	NI	1990 5.4
Optimistic case:											
1976	73.0	NI	14.7	39.6	18.7	NI		NI	NI	NI	1976 5.7
1980	83.4	NI	14.6	47.5	20.3	NI	1975-80 5.0%	NI	NI	NI	1980 6.4
1985	95.8	NI	15.8	59.1	20.9	NI	1980-85 3.5%	NI	NI	NI	1985 4.4
1990	107.6	NI	17.2	68.5	21.5	NI	1985-90 3.0%	NI	NI	NI	1990 4.0

See footnote at end of table.

TABLE 5.—SUMMARY TABLE OF 6 ENERGY DEMAND FORECASTS—Continued

	In quadrillion Btu										
			Sectoral energy use								
	Gross energy use	Net energy use	Household and commercial	Industrial	Transportation	Population (million)	Gross national product (million dollar)	Energy/GNP ratio (thousand Btu per dollar)	Energy/capita ratio	Unemployment rate (percent)	Inflation rate (percent)
Energy outlook, 1977–90 (Exxon, 1977):									(Thousand Btu per person)		
1977	76.4	NI	25.8	31.0	19.6	NI	3.5%	NI	NI	NI	NI
1980	82.6	NI	28.6	33.2	20.9	NI	annual	NI	NI	NI	NI
1985	94.9	NI	34.1	38.3	22.5	NI	growth	NI	NI	NI	NI
1990	109.9	NI	40.4	44.8	24.7	NI	rate	NI	NI	NI	NI
National energy outlook (FEA, 1976):											
Reference case:											Average annual rates as measured by the CPI
$8 oil:						Average annual growth rates					
1974	73.1	NI	13.9	40.8	18.4	1975–80 0.9%	1975–80 5.5%	NI	NI	1975 8.9	1975–80 5.2
1980	85.4	NI	14.1	50.0	21.4			NI	NI	1980 6.6	
1985	103.4	NI	16.7	61.5	25.2			NI	NI	1985 5.6	
1990	121.7	NI	18.7	74.3	28.6			NI	NI	1990 4.9	
$13 oil:											
1974	73.1	NI	13.9	40.8	18.4	1980–85 1.0%	1980–85 3.6%	NI	NI	-------------	1980–85 4.8
1980	81.6	NI	12.7	48.8	20.1			NI	NI	-------------	
1985	98.9	NI	14.8	60.8	23.2			NI	NI	-------------	
1990	116.1	NI	16.6	74.1	25.3			NI	NI	-------------	
$16 oil:											
1974	73.1	NI	13.9	40.8	18.4	1985–90 0.9%	1985–90 3.0%	NI	NI	-------------	1985–90 3.9
1980	80.2	NI	12.2	45.4	19.6			NI	NI	-------------	
1985	97.3	NI	14.1	61.9	22.2			NI	NI	-------------	
1990	114.0	NI	15.5	74.2	24.2			NI	NI	-------------	
Energy demand studies of major consuming countries (MIT/WAES, 1977):							Average annual growth rate				
1972, 1985	71.6	53.1	15.6	20.5	17.0	NI	1976–85	NI	NI	NI	-------------
Case B	80.7	5.92	14.7	26.8	17.7	NI	3.2%	NI	NI	NI	4.2
Case E	106.9	76.5	20.8	34.5	21.2	NI	4.4%	NI	NI	NI	4.8
U.S. energy through the year 2000 (BOM, 1976):							In 1958 dollars	GNP in 1958 dollars			
1974	71.3	59.9	17.5	24.1	18.3	212	821	89	283	NI	NI
1980	87.1	68.9	21.6	25.9	21.4	224	1,092	80	308	NI	NI
1985	103.5	77.5	24.6	2[illegible].8	24.1	236	1,294	80	328	NI	NI
2000	163.4	110.2	34.6	43.5	32.2	264	2,105	77.6	417	NI	NI

[1] NI means not indicated.

Present and Future Domestic Supply of Oil and Natural Gas Liquids

(By Joseph P. Riva, Jr.*)

The vital role played by oil in modern industrial society justifies the characterization of this century as the oil age. Although other forms of energy can largely replace oil, at a price, its importance to our current economy and way of life make an understanding of its availability in the future essential. Oil is a resource that is not being formed or replaced at a rate that has any significance relative to its rate of consumption and, it is appropriate to consider how much is left and how much may be produced.

DOMESTIC PETROLEUM RESERVES

Proved petroleum reserves are those quantities of in-place oil (measured in terms of stock tank barrels of 42 U.S. gallons at atmospheric pressure, and corrected to 60 degrees Fahrenheit) that have been identified and are considered, on the basis of geological and engineering knowledge, to be recoverable under the current economic conditions with existing technology. Thus, either higher prices or improved recovery technology (or both) will increase petroleum reserves. It has been estimated that the crude oil price rises from March 1973 to the end of 1974 increased domestic reserves from five to six percent (or about 1.8 to 2.2 billion barrels).[1] This was due to the longer life of producing oil wells made possible by an average price rise from $3.39 to $6.85 per barrel, and also to increased infill drilling, more rapid development of previously marginal deposits, and wider use of enhanced recovery operations, all triggered by the higher prices.[2]

However, in spite of increasing prices and a sharp increase in drilling activity, total proved reserves have continued to decline during 1974, 1975, and 1976. This decline, which began in 1971, is the result of new discoveries not keeping pace with domestic production. The December 31, 1976, reserve estimates, released by the American Petroleum Institute, indicate a domestic proved crude oil reserve of 30.9 billion barrels, down 1.7 billion barrels from the previous year, which can be compared to a decrease of 1.6 billion barrels in 1975. Almost 1.1 billion barrels of oil were added to proved reserves in 1976 through the discovery of new fields, the extension and development of known fields, and the revision of earlier estimates. However, during the year about 2.8 billion barrels of crude oil were produced, leaving a net reduction of 1.7 billion barrels.

Proved reserves of natural gas liquids (hydrocarbons present in gaseous form or in solution with reservoir oil that are recoverable as

*Joseph P. Riva is a specialist in earth sciences at the Congressional Research Service.
[1] Higher Crude Prices Add Sharply to U.S. Reserves. The Oil and Gas Journal, Jan. 20, 1975, p. 31.
[2] Ibid.

liquids by condensation or absorption processes) were estimated by the American Gas Association to have increased from 6.267 (in 1975) to 6.402 billion barrels (in 1976), a two percent increase. Natural gas liquids production of 0.701 billion barrels in 1976 was unchanged from the previous year.

The American Petroleum Institute also estimated that it may be possible to produce an additional 4.3 billion barrels of oil by successfully utilizing specialized recovery techniques in all known reservoirs. This estimate is nearly 0.7 billion barrels less than last year mostly because of the transfer of some reservoirs into the "proved" category following the application of such techniques.

The drop in proved reserves of crude oil continued a steady decline which has been evident over the past several years and which has been broken only by the Alaskan North Slope discoveries. The later declines, moreover, have been registered in spite of sizable increases in the number of wells drilled. Drilling activity in 1976 totaled 39,765 completed wells, the highest level since 1964, but considerably short of the peak drilling year of 1956 when 57,111 wells were drilled. Another gage of the pace of domestic drilling activity is that in 1975, 81.3 percent of the total Free World well completions were in the United States. In Saudi Arabia only 210 wells were drilled (0.4 percent).

The reliability of estimates of the proved productive volumes of new discoveries or of partially developed reservoirs varies according to the amount of geological information that is available at the time the estimate is being made. Such necessary factors as the areal extent of the geological structure, the average thickness of the producing reservoir, the oil column within the reservoir, and the continuity of the reservoir characteristics cannot be determined accurately without sufficient subsurface information. The ultimate size of newly discovered reservoirs (in old or new fields) is seldom determined in the year of discovery. Thus, first-year estimates of proved reserves in new reservoirs are often smaller than the total that will eventually be assigned, resulting in estimates of ultimate recovery and of original in-place oil for recently discovered fields often being revised substantially upward in subsequent years on the basis of information provided by additional drilling, production performance, and the use of improved enhanced recovery techniques.

Inferred reserves are those reserves, in addition to proved reserves, which should eventually be added to proved reserves through extensions, revisions, and new pays in known fields. Inferred reserves are estimated by extrapolating the rate of growth of discovered petroleum volumes for each region of the United States by use of correction factors based upon the time lapse since the initial year of discovery. The wide variability in the data used to determine rate of growth of petroleum discoveries and the fact that proved reserves are also estimates causes a significant degree of uncertainty in the calculation of inferred reserves. Inferred oil reserves in the United States were calculated by the U.S. Geological Survey at 23.1 billion barrels at the end of 1974. Current figures are put between 14 and 20 billion barrels. Thus, if inferred reserves of oil are added to proved reserves (30.9 billion barrels), as much as 51 billion barrels of discovered domestic oil may currently await production.

The reserve figure compiled by the American Petroleum Institute and the American Gas Association are generally accepted by industry and government as being reliable estimates of domestic oil and gas liquid reserves. These figures are used by the U.S. Geological Survey to derive their statistics for measured and indicated hydrocarbon reserves.[3] The Federal Energy Administration estimated U.S. proved reserves at the end of 1974 in a report to the President issued on October 31, 1975. Based on a survey of all oil and gas field operators in the United States, the report estimated the domestic proved crude oil reserves at about ten percent above the American Petroleum Institute's 1974 estimate. The two estimates were considered by the Federal Energy Administration to vary by no more than a factor which may be expected when comparing estimates from different sources.[4] About half of the difference between the crude oil reserve figures of the Federal Energy Administration and those of the American Petroleum Institute can be attributed to the Federal Energy Administration's inclusion of two billion barrels of heavy crude oil which the American Petroleum Institute did not count because it was not recoverable without the use of enhanced recovery methods.[5]

The Federal Government is being urged by the oil and gas industries to assume the task of collecting and reporting hydrocarbon reserve information. Oil industry spokesmen have informed the Office of Management and Budget that collecting reserves information, analyzing it, and preparing reports is properly a Government function and that both the American Petroleum Institute and the American Gas Association would like to work their way out of the job.[6] Both organizations have recommended that a single lead Federal agency be designated to collect and disseminate proved reserves information. No agency was endorsed, but one with the technical expertise to understand reserves information (such as the U.S. Geological Survey) was favored. It was also recommended that the data be gathered annually from the operators rather than from the owners, as the operators have the most complete information, and also that the data be limited to proved reserves. A further recommendation is that the data should be verified for each field by independent consultants.

The President's National Energy Plan contains a proposal for a three-part energy information program. It would include a Petroleum Production and Reserve Information System. Under this proposal, the Federal Government would assume the data collection responsibilities now performed by the American Petroleum Institute and the American Gas Association. Federal officials would supervise the collection and preparation of reserve data with the information collected and submitted to the Federal Government verified and randomly audited at the company level. Existing law regarding the protection of confidential proprietary information would not be changed.[7]

---

[3] Miller, Betty M. et. al. Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States. Geological Survey Circular 725, Reston, Virginia, 1975, p. 2.

[4] Oil and Gas Resources, Reserves, and Productive Capacities. Federal Energy Administration, Final Report, Volume I. Washington, D.C., October 1975, p. 1.

[5] FEA Lists Higher U.S. Reserve Figures. The Oil and Gas Journal, July 7, 1976, p. 32.

[6] Industry Urges U.S. to Collect Reserves Data. The Oil and Gas Journal, Aug. 2, 1976, p. 53.

[7] The National Energy Plan. Executive Office of the President, Energy Policy and Planning, Apr. 29, 1977, p. 85–86.

UNDISCOVERED DOMESTIC PETROLEUM RESOURCES

To put oil production into perspective, half of all of the oil that has ever been produced has been taken from the Earth in the past ten years. Even in OPEC countries, and especially in the United States, most of the oil has already been found. So great is the accelerating demand for energy that the years of abundant petroleum supply at supportable prices will be relatively few, causing, among other things, an increased urgency in estimating the amount of remaining undiscovered hydrocarbon resources in order to better formulate energy policy.

The amount of petroleum recoverable from a sedimentary basin is determined by the volume originally generated from the indigenous organic matter and by the geologic history of the basin. The amount of oil theoretically formed may be estimated from the volume and quality of the source rock and then all available lithologic, tectonic, hydrodynamic, and physical data can be employed to arrive at a projection of the quantities which may be expected to be reservoired and ultimately recovered. However, any such volumetric estimates necessarily have a low reliability and should be regarded as a dated assessment based on the state of existing knowledge. All such estimates depend upon geologic projections in which great and unappraised uncertainty is involved such that a relatively small and unexpected change in the thickness of a source bed or in the continuity of a reservoir horizon can affect a resource estimate in a partly explored region by a very large factor. Another reason for the generally low reliability of estimates of potential hydrocarbon resources is that not enough is currently known about the Earth's crust or the frequency of hydrocarbon distribution or concentration to estimate all that may geologically be available. Also, it is not possible to forecast with much confidence either the technological advances or the economic and legislative changes that may determine eventual production. However imperfect, projections of undiscovered petroleum resources are of importance in understanding present conditions and are necessary for the formulation of future energy policy.

There are three methods of hydrocarbon resource estimation. These are the sediment volumetric method, the combined geologic-analogy and statistical model method, and the past performance or behavior extrapolation method. The sediment-volumetric method is a projection of the amount of oil known to exist in a developed region to an unknown region of apparently similar geologic character. Even though very unfavorable rocks are not included in the projection, this method frequently leads to overly optimistic hydrocarbon resource estimates, especially when it is assumed that undrilled rock volumes in little known areas may contain the same amount of oil as an equal volume of rock which has already been drilled in a producing area. This assumption does not recognize that much of the exploration potential of undrilled areas, especially onshore in the lower 48 States, has already been geologically discounted by the industry. These one-to-one comparisons have sometimes been reduced by one-half in more recent estimates, but even the one-half value may lead to resource projections that are too high.

The most recent U.S. Geological Survey method includes the extrapolation of known producibility into untested sediments of similar geology. However, it also includes volumetric techniques using geologic analogs with the setting of upper and lower yield limits through comparisons with a number of known areas; volumetric estimates with an arbitrary general yield factor, used when direct analogs are not known; a graded series of potential-area categories; and a comprehensive comparison of all published estimates for each area to all estimates generated by the above methods.[8] Individual and collective appraisals are made for each region and Monte Carlo approximation techniques are applied to derive the probability function for the amount of undiscovered petroleum in each region and for the summation of subtotals of the regions of the United States.[9] The estimates for undiscovered recoverable hydrocarbons in this most recent Geological Survey effort are given as a range, the low value of which is the quantity associated with a 95 percent probability (a 19 in 20 chance) that there is at least this amount of hydrocarbons. The high value is the quantity with a five percent probability (a 1 in 20 chance) that there is the higher amount.

The Survey procedure described above is an example of a combined geologic analogy and statistical model estimation method as is the Mobil Oil Company method which employs a probabilistic exploration-engineering analysis in areas where sufficient data are available. Computer input for Mobil's hydrocarbon resource estimation uses a Delphi-like approach in which input estimates are challenged to bring out the basis of the estimates and to improve their quality. Many possible combinations of the various geological inputs are obtained and the result is a probability distribution of the hydrocarbon potential of a given area.[10]

Past performance or behavioristic extrapolation methods are based on the extrapolation of past experience with such indicators as discovery rates; cumulative production or productive capacity curves; and the fitting of past performances, by the use of mathematical derivations, into logistic curves which can be projected into the future. A decline in any of the chosen parameters could signal a declining resource base, however, these techniques are less valid in frontier regions where little history exists or in areas that are not geologic or economic replicas of the historical model.[11] In general, these methods are most applicable in the later stages of hydrocarbon exploration in mature areas such as the lower 48 States. The M. King Hubbert growth curve projections have proven relatively accurate in the forecasting of the domestic crude oil production peak. In the mid-1950's the domestic petroleum industry had been in operation for just under 100 years and cumulative oil production had amounted to about 52 billion barrels. If future production were to total two or three times past production, it was felt that there was little to worry about for many years. However, at that time Hubbert, by use of his oil production curves with a figure of from 150 to 200 billion barrels for ultimate domestic crude oil production,

[8] Miller, Betty M. et. al., op. cit., p. 20.
[9] Ibid., p. 25.
[10] World Crude Resource May Exceed 1,500 Billion Barrels, World Oil, September 1975, p. 56;
[11] Miller, Betty M. et. al., op. cit., p. 18.

arrived at a projection for domestic production to peak between 1966 and 1971 (depending upon whether the 150 or 200 billion barrel figure was used). Domestic oil production peaked in 1970, about as Hubbert predicted.

In any projection of undiscovered petroleum resources, however, the practical consideration is how much oil and gas can be found, rather than how much is left to be found. An uncaptured resource provides no benefits. It may be that more undiscovered domestic oil exists onshore than offshore, but the chances of finding large fields onshore in the lower 48 States are small. Only five fields of over 100 million barrels were found onshore in the lower 48 States by the 38,000 exploratory wells drilled in the first half of this decade.[12] The attractiveness of the offshore is that it may yield oil in large accumulations and thus the oil may be found and translated into large volume production sooner and with less drilling effort than in the picked over onshore oil regions.

There are a number of recent estimates of undiscovered domestic crude oil resources. The following table contains a selection of these which have been chosen to illustrate the methods of estimation previously discussed and the evolution of more conservative projections which can be accounted for by better methods and also by the realization of the importance of such estimates in energy policy decisions.

TABLE 6.—*Undiscovered domestic crude oil resources*

Estimate	*Billion barrels*
U.S. Geological Survey:	
Zapp (1962)	590
McKelvey (1974)	200–400
Miller (1975)	50–127
Hubbert (1974)	72
National Academy of Sciences (1975)	113
Mobil (1974)	88
Exxon (1976)	118

The 1962 and 1974 Geological Survey estimates were made on the basis of volumetric and geological province analysis which assumed that an equal volume of oil would be found in equal amounts of drilled and undrilled sediments. Even if this assumption is halved, the results of such an analysis would tend to be relatively high because the most promising areas are drilled first and the sediments in the lower 48 States (onshore) which remain undrilled (after 100 years and 2½ million wells) are those which, for a number of geologic and economic reasons, do not appear very promising. Also, since 80 percent of current world oil production comes from giant fields, it does not take very many dry holes to determine that a given sedimentary basin will not be an outstanding oil producer. Small field production is always welcome, but cannot be expected to substantially increase the energy position of as large a consumer state as the United States. The large resource figures of Zapp (1962) were the result of volumetric analysis made at a time when few were interested in undiscovered oil resource projections. The 1975 figures of the Geological Survey and the figures of Mobil and Exxon were derived by more sophisticated combined geological and statistical models. These and the projections of Hubbert (which result from extrapolations of past

[12] Drummond, Jim. The IADC Meeting in Dallas. The Oil Daily, Sept. 22, 1975.

production performance) and the National Academy of Sciences are more conservative and, thus, safer projections on which to base energy policy. In the presence of exponential growth in consumption, even a doubling of the lower domestic oil resource figures would only put off the period of transition from petroleum to other sources of energy, but the transition must come rather soon in a relative sense.

What is still unknown is the offshore. Only about three percent of the Nation's continental shelf has been drilled. This area could help to change the conservative resource figures if giant fields were found. There is no way at present to know how much or how little petroleum exists offshore, but a few hundred wells drilled there will reveal more information pertaining to our petroleum resource base (or lack thereof) than thousands more drilled onshore.

DOMESTIC PETROLEUM PRODUCTION

Production of petroleum liquids in the United States steadily increased until it peaked in 1970 at 4.1 billion barrels. From 1970 annual production has gradually declined to about 3.5 billion barrels both in 1975 and 1976. Production of oil and natural gas liquids in the traditional producing areas of the lower 48 states is expected to continue its decline, but Alaskan and offshore production is expected to increase. There have been a number of projections of expected domestic oil production, some of which are given in the table below.

TABLE 7.—DOMESTIC LIQUID PETROLEUM PRODUCTION PROJECTIONS

[Billion barrels per year]

	1980	1985	1990
CRS Industry Survey (1977)	3.8	4.0	4.2
The National Energy Plan (1977)		3.3–4.0	
CBO Critique of National Energy Plan (1977)	3.7		
CIA (1977)	3.6	3.6–4.0	
OECD (1977)	3.9	4.2–5.1	
Exxon (1977)	3.6		4.3
Shell (1976)	3.8	4.0	4.4
FEA (1976)	5.0	5.4–5.9	[1] 5.0
U.S. Bureau of Mines (1975)	4.3	5.3	[2] 5.0
Department of Commerce (1975)		4.0–4.9	

[1] 1989.
[2] 2000.

The above projections, of course, have been made under various assumptions. The CRS petroleum industry survey asked the responding companies to make their projections under the following political assumptions: (1) decontrol of the price of all domestic oil after May 1979, with no new windfall profits taxes added; (2) decontrol of new natural gas; (3) continuation of the current outer continental shelf leasing system; (4) an annual average of 1.5 to 2 million acres of the outer continental shelf leased to the industry; (5) no vertical divestiture; and (6) Naval Petroleum Reserve No. 4 to be leased by the Department of the Interior on terms similar to the offshore leasing. The National Energy Plan model projects a total U.S. production of around 4.0 billion barrels per year in 1985, but states that the actual production could be as low as 3.3 billion barrels. The higher FEA figures for 1985 are based on a price of $16 per barrel, while the lower figures are based on a $13 per barrel price.

21-616—78——4

While most oil production projections present a base case, there is often also included in the study an accelerated case, a business as usual case, a low estimate, or a range of projections. While it is obvious that it is not possible to estimate future oil production with certainty, given the complexity of the matter and the numerous unknowns, and it is also obvious that economics and especially Federal governmental decisions will play an important role in determining future oil production levels; it is important to consider the geological and technological constraints, if any, that are connected with the current projections.

The projections given in the table for 1980 petroleum production, with the exception of the older FEA and Bureau of Mines estimates, are, in general, very close to the CRS industry survey figure of 3.8 billion barrels per year (10.4 million barrels per day). The 1985 figures for the more recent studies are in the area of 4.0 billion barrels per year (11 million barrels per day) which also is the estimate of the National Energy Plan as well as the result of the CRS Industry Survey. The estimates of the older studies tend to be higher, perhaps because the domestic petroleum resource base was considered to be larger a few years ago and also because a generally more optimistic view of the Nation's energy future may have prevailed then.

To determine the resource base and drilling effort needed to support a domestic production of 3.8 billion barrels of oil per year in 1980, the following considerations are necessary: (1) 14.6 billion barrels of oil will be produced from 1977 to 1980, and (2) 38.0 billion barrels of reserves will be needed to maintain a 10 to 1 reserve/production ratio in 1980. (Physical constraints generally limit annual withdrawal to an amount equal to a production-to-reserve ratio of approximately 1 : 10). Thus, total petroleum needed by 1980 to attain a production of 3.8 billion barrels would be 52.6 billion barrels (14.6 + 38.0). The liquid petroleum reserve as of the end of 1976 was 37.3 billion barrels and to this can be added 0.1 billion barrels which are estimated by the National Petroleum Council to be added to recovery by use of enhanced recovery methods in 1980. Thus 15.2 billion barrels [52.6–(37.3 + 0.1)] will have to be added to reserves by 1980 to support the 3.8 billion barrel per year production estimate while maintaining a 10 to 1 reserve ratio. A part of this petroleum will come from revisions and extensions of existing fields (inferred reserves), but by the 1980's a greater part must come from new field discoveries.

In 1976, 39,765 wells were necessary to add 1.9 billion barrels to reserves. To meet a domestic production of 3.8 billion barrels in 1980 while maintaining a 10 to 1 reserves ratio, it will be necessary to add about 3.8 billion barrels of petroleum liquid reserves per year during each of the next four years. While a portion of this will come from extensions and revisions of known fields (inferred reserves) it would appear that a record amount of drilling would be required to increase reserves at such rates, especially from onshore in the lower 48 states. According to the U.S. Geological Survey between 29 and 64 billion barrels of oil remain to be discovered in the lower 48 States onshore. If the lower figure proves correct, it would be necessary to discover a very substantial portion of all the remaining onshore lower 48 state oil in the next four years. This would almost certainly prove

to be impossible. The offshore and Alaska, however, offer areas in which undiscovered giant fields may still exist. It is these very large fields that offer the possibility of rapid and more efficient development which may meet the projections given above, however, this development must begin at once given the lead times involved. What could happen between now and 1980 is that domestic drilling would continue to increase, though not at a rate nor in the proper locations (the frontier areas) to result in discoveries sufficient to support a 1980 production of 3.8 billion barrels. However, some reserves would be added through revisions and new discoveries and, with North Slope Alaska production added, the result could be increased domestic production. Also, should prices rise significantly, a small amount of additional oil (over the 0.1 billion barrels per year cited) may be realized from enhanced oil recovery methods. However, the lead times of enhanced recovery projects are such that very little can be done in so short a time.

The resource base and drilling effort needed to support a projection of a production of 4.0 billion barrels of oil in 1985 can be determined as follows: (1) 34.1 billion barrels of oil will need to be produced from 1977 to 1985; and (2) 40.0 billion barrels of oil reserves will be needed to maintain a 10 to 1 reserve/production ratio in 1985. Thus, the total domestic petroleum needed by 1985 to attain a production of 4.0 billion barrels would be 74.1 billion barrels (34.1 + 40.0). Current liquid petroleum reserves at the end of 1976 totaled 37.3 billion barrels and to this figures 0.3 billion barrels could be added to recovery by 1985 by advanced enhanced recovery methods (as estimated by the National Petroleum Council). Thus, 36.5 billion barrels [74.1 — (37.3 + 0.3)] will have to be added to reserves by 1985 to support the 4.0 billion barrel per year production estimate for that year while at the same time maintaining a 10 to 1 reserve ratio. A part of this petroleum will come from revisions and extensions of existing fields (inferred reserves), but by 1985 most will have to come from new field discoveries. In order to meet the production projection of 4.0 billion barrels in 1985, with a 40 billion barrel reserve, it will be necessary to add 4.1 billion barrels per year for the next nine years. Some of this additional oil may come from enhanced recovery (the National Petroleum Council's high estimate for 1985 is 0.6 billion barrels), but even this figure will not make up the entire shortfall. Since 1948, there has only been one year that reserves have increased more than three billion barrels. This was the 9.6 billion barrel increase in 1971, caused by the inclusion of the Prudhoe Bay, Alaska, reserves. In the absence of such fortunate finds of giant fields in the frontier areas, it will be very difficult, if not impossible, to reach the 4.0 billion barrel projection for 1985 production.

Present and Future Domestic Supply of Natural Gas

(By Joseph P. Riva, Jr.)

Natural gas is closely related to crude oil and is formed under similar geological conditions. The decomposition of organic matter, with the aid of bacteria, in an oxygen poor environment results in the formation of methane and other hydrocarbons. Chemically, natural gas is mostly methane, but it may also contain small amounts of other hydrocarbons along with a few other gases. Natural gas is often dissolved in oil at the high pressures existing in the reservoir and is separated from the oil after extraction from the well. It also can be obtained from gas wells drilled into reservoirs which contain natural gas but no oil; and from reservoirs in which it occurs above the oil, but is not dissolved in it.

For many years the United States had a surplus of natural gas. This surplus resulted from the discovery of many gas fields during the search for oil. Initially, local gas markets were not able to utilize all of the available gas supply; but the rapid expansion of long-distance interstate pipelines after World War II, consumer preference for this fuel, price controls on natural gas, and the recent downward trend of reserves developed in relation to production have combined to produce the present natural gas shortage.

The production of natural gas is of a much higher efficiency than the production of oil. Depending upon the permeability of the reservoir, recovery can be as high as 75 to 80 percent of the original in-place gas (compared to an average one-third of the oil). There are, however, appreciable amounts of natural gas in formations with permeabilities so low that the gas cannot be produced economically. The Energy Research and Development Administration has estimated that 600 trillion cubic feet of natural gas is known to exist which cannot now be recovered commercially, but that as much as 250 trillion cubic feet of this gas might eventually be recovered with enhanced recovery techniques.[1] This gas is not, of course, counted in compilations of proved natural gas reserves.

DOMESTIC NATURAL GAS RESERVES

Proved natural gas reserves are the total volume of natural gas estimated to be recoverable from known reservoirs under the economic and operating conditions existing at the time of the estimate. Such volumes of gas are expressed in cubic feet at an absolute pressure of 14.73 pounds per square inch and a temperature of 60 degrees Fahrenheit.

[1] A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future. Volume 1: The Plan, ERDA 76-1, U.S. Government Printing Office, Washington, D.C., Apr. 15, 1976, p. 51.

Proved reserves of natural gas were estimated at 216 trillion cubic feet as of December 31, 1976, by the American Gas Association. The 1976 figure was lower than the estimate of the previous year by 12.2 trillion cubic feet (5 percent), and marked the sixth straight year of natural gas reserves decline. Only the discovery of 26 trillion cubic feet of gas in Alaska (Prudhoe Bay), first reported in 1970, kept last year's decline from being the ninth consecutive drop in reserves. For the lower 48 States, the 1976 gas reserve figure of 184.1 trillion cubic feet is the lowest reserve level since 1949, when gas production was only 32 percent of current levels. Total reserve additions of 7.56 trillion cubic feet in 1976 were the second lowest additions to reserves since 1946. For six years, 1969 to 1974, natural gas production exceeded 20 trillion cubic feet per year while reaching a peak of 22.7 trillion cubic feet in 1972. Natural gas production in 1976 was 19.5 trillion cubic feet, 16 percent below the 1972 high and 0.2 trillion cubic feet below 1975 production.

Estimates of proved natural gas reserves as compiled by the American Gas Association are considered to be those which an analysis of geologic and engineering data demonstrates, with reasonable certainty, to be recoverable in the future from known reservoirs under existing economic and operating conditions. Reservoirs are considered proved if they have demonstrated the ability to produce gas either by actual production or by conclusive formation testing. The area of a reservoir considered proved is the portion delineated by drilling and further defined by gas-oil or gas-water contacts or limited by structural or stratigraphic features.

The proved reserve estimates made by the American Gas Association are generally accepted throughout the industry and the Government as being reliable estimates of domestic oil and gas reserves.[2] The Federal Energy Administration estimated U.S. oil and gas reserves as of December 31, 1974, in a report to the President issued on October 31, 1975. Based on a survey of all oil and gas field operators in the United States, it was estimated in the report that domestic proved natural gas reserves totaled 240.2 trillion cubic feet. This estimate of the Federal Energy Administration varied from that of the American Gas Association (for the same date) by 2.9 percent, less than may be expected when comparing estimates from different sources.[3]

Because the results of the Federal Energy Administration study showed that a government assessment of industry data can provide a reliable estimate of reserves, the Federal Government is being urged by the oil and gas industry to take on the task of collecting and reporting hydrocarbon reserve data; and the President's National Energy Plan contains a proposal to assume the data collection responsibilities now performed by the American Gas Association and the American Petroleum Institute.

Inferred gas reserves are those reserves, in addition to proved reserves, which should eventually be added to proved reserves through extensions, revisions, and new production zones in known gas fields. Inferred reserves are estimated by extrapolating the rate of growth

[2] Miller, Betty M. et. al. Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States. Geological Survey Circular 725, Reston, Va., 1975, p. 2.

[3] Oil and Gas Resources, Reserves, and Productive Capacities. Federal Energy Administration, Final Report, Volume I, Washington, D.C., October 1975, p. 1.

of discovered gas volumes on a regional basis by use of correction factors based upon the time lapse since the initial year of discovery. The wide variability in the data used to determine rate of growth of gas discoveries and the fact that proved gas reserves are also estimates, causes a significant degree of uncertainty in the calculation of inferred reserves. The U.S. Geological Survey estimated domestic inferred gas reserves at 201.6 trillion cubic feet at the end of 1974. The current figure would be well under 200 trillion cubic feet. Thus, if current inferred reserves are added to current proved reserves, about 400 trillion cubic feet of discovered domestic gas may currently await production.

UNDISCOVERED DOMESTIC NATURAL GAS RESOURCES

The three basic methods of hydrocarbon estimation used for oil and described in the chapter "Current Views of the Present and Future Domestic Supply of Oil and Natural Gas Liquids" are also used for projections of undiscovered natural gas resources. As is the case with oil resource estimates, undiscovered natural gas resource estimates necessarily have a low reliability for they depend upon geologic projections in which great uncertainty is involved. Another reason for the generally low reliability of the estimates is that it is not possible to forecast with surety either the technological advances or the economic changes that may determine eventual production. However, imperfect as they are, projections of undiscovered oil and gas resources are of importance in understanding present conditions and are necessary for the formulation of future energy policy.

There are a number of recent estimates of undiscovered domestic natural gas resources. The following table contains a selection of estimates that have been chosen to illustrate differing methods of projection and the evolution of more conservative figures, which can be accounted for by better methods and also by the realization of the importance of such estimates in energy policy decisions.

TABLE 8.—*Undiscovered domestic natural gas resources*

Estimate	*Trillion cubic feet*
U.S. Geological Survey:	
McKelvey (1974)	990–2000
Miller (1975)	322–655
Hubbert (1974)	540
National Academy of Sciences (1975)	530
Mobil (1974)	443
Exxon (1976)	582

The 1974 Geological Survey estimate was made on the basis of an assumption that an equal volume of gas would be found in equal amounts of drilled and undrilled sediments (with areas judged unsuitable for gas excluded). Even if this assumption is halved, the results would still tend to be high, because the most geologically promising areas are drilled first, especially in the lower 48 States which have been explored with some 2½ million wells in the past 100 years. The 1975 figures of the Survey and those of Mobil and Exxon were derived by a more sophisticated combination of geological and statistical models. These and the projections of Hubbert (which result from extrapolation of past production performance) and the National Academy of Sciences are more conservative and, as such, are safer projections on which to base energy policy.

DOMESTIC NATURAL GAS PRODUCTION

Production of natural gas in the United States, after reaching a peak of 22.7 trillion cubic feet in 1972, has declined steadily to 19.5 trillion cubic feet in 1976. There have been a number of projections of expected domestic natural gas production, some of which are listed in the table below.

TABLE 9.—DOMESTIC NATURAL GAS PRODUCTION PROJECTIONS

[Trillion cubic feet per year]

	1980	1985	1990
CRS Industry Survey (1977)	17.4	16.9	16.9
The National Energy Plan (1977)	18.0	17.0	16.0
CIA (1977)	17.2–18.4	16.3–18.2	
OECD (1977)	17.5	19.2–22.2	
Exxon (1977)	15.6	15.4	15.0
Shell (1976)	17.5	16.5	14.0
FEA (1976)		17.0–22.3	
U.S. Bureau of Mines (1975)	19.0	18.2	[1] 16.5
Department of Commerce (1975)		21–24	

[1] 2000.

The above projections have been made under a variety of assumptions. The CRS industry survey asked the responding companies to make projections under the following political assumptions: (1) decontrol of the price of all domestic oil after May 1979, with no new windfall profits taxes added; (2) decontrol of new natural gas; (3) continuation of the current outer continental shelf leasing system; (4) an annual average of 1.5 to 2 million acres of the outer continental shelf leased to the industry; (5) no vertical divestiture; and (6) Naval Petroleum Reserve No. 4 to be leased by the Department of the Interior on terms similar to the offshore leasing. Under the National Energy Plan, new gas would be priced at approximately $1.75 per thousand cubic feet by 1978 with the possibility in the mid-1980's of establishing full market price. The FEA figures are based on a gas price ceiling of $1.00 per thousand cubic feet (lower figure) to a reference case (with conservation) of $2.13 per thousand cubic feet (higher figure). Most projections of natural gas production present a base case along with other cases such as accelerated, business as usual, and/or a low estimate. It is not possible to estimate future natural gas production with certainty, given the many unknown factors that will enter into the final production levels. Economics and Federal governmental decisions will, of course, play an important role, but it is also necessary to consider the geological and technological constraints, if any, that may be connected with the above projections.

The projections in the table for 1980 average 17.5 trillion cubic feet per year. To determine the resource base and the drilling effort needed to support a domestic natural gas production of 17.5 trillion cubic feet in 1980 the following considerations are necessary: (1) 73 trillion cubic feet of natural gas will be produced from 1977 to 1980, and (2) 210 trillion cubic feet of reserves will be needed to maintain a 12 to 1 reserve/production ratio in 1980. The total amount of natural gas needed by 1980 to sustain a declining production to 17.5 trillion cubic feet would be 283 trillion cubic feet (73 + 210). The natural gas reserve at the end of 1976 was 216 trillion cubic feet. Thus 67

trillion cubic feet (283 — 216) of gas would have to be added to reserves by 1980 to support a 17.5 trillion cubic feet per year gas production estimate, while maintaining a 12 to 1 reserve ratio. Much of this gas will come from revisions and extensions of known gas fields, but an average of 16.75 trillion cubic feet of gas still must be added to reserves every year for the next four years. This can be contrasted to total additions of only 7.56 trillion cubic feet last year and 10.7 trillion cubic feet in 1975 (the best figure since 1970). Increased drilling will probably be of some help, but the last two years were years of relatively high drilling activity. It is difficult to envision a 1980 production level of 17.5 trillion feet in the absence of the discovery of giant gas fields or the drawing of reserves below the 12 to 1 ratio. The additional 67 trillion cubic feet needed represents about 20 percent of the undiscovered, recoverable, onshore lower 48, State, natural gas resource as estimated by the U.S. Geological Survey.

The resource base and drilling effort needed to support the 1980 estimated production at a level 17.5 trillion cubic feet per year to 1985 can be examined as follows: (1) 160.5 trillion cubic feet of natural gas will be produced from 1977 to 1985, and (2) 210 trillion cubic feet will still be needed to maintain a 12 to 1 reserve/production ratio in 1985. Thus, the total amount of gas required to meet the projection would be 370.5 trillion cubic feet (160.5+210). The natural gas reserve at the end of 1976 was 216 trillion cubic feet, thus 154.5 trillion cubic feet of natural gas (370.5 – 216) would have to be added to reserves by 1985 to support the 17.5 trillion cubic feet per year production estimate, while maintaining a 12 to 1 reserve ratio. Again, some of this gas will come from extensions and revisions of known fields (inferred reserves) and perhaps by 1985 some also may come from enhanced recovery of gas from tight formations or from geopressured waters that can not now be commercially produced, but an average of 17.2 trillion cubic feet of gas will have to be added each year for the nine year period. Not since the North slope discoveries has more than 17.2 trillion cubic feet of natural gas been added to reserve figures (1976 additions were 7.56 trillion cubic feet). Also, the 154.5 trillion cubic feet of gas required represents almost half of the undiscovered recoverable natural gas resource estimated by the Geological Survey to be present in the lower 48 States, onshore. It would appear that even with a marked increase in drilling, the drawing down of gas reserves below the 12 to 1 ratio, and some exploitation of tight gas sands or geopressured deposits, the maintaining of a level 17.5 trillion cubic feet natural gas production to 1985 will be very difficult. It is probable that discoveries of giant gas fields in frontier areas would be necessary to meet this projection. Actually, the average of all estimates given in the table for 1985 gas production is 18.2 trillion cubic feet per year. However, since most estimates projected a decrease in production by 1985, the level figure of 17.5 was chosen for the example. Should the higher figure be used, obviously more gas would have to be found.

Coal Demand and Supply Through 1985

(By Herman T. Franssen*)

INTRODUCTION

Coal is the most abundant energy resource in the U.S. (constituting 90% of current total U.S. fossil fuel reserves). At current demand levels, we have enough coal reserves to last at least 300 years and, at FEA's projected 1985 production levels in the National Energy Outlook of 1976, coal reserves could last 150 or more years.

Throughout the 19th century coal production increased gradually, and by the turn of the century, coal supplied 90 percent of the U.S. energy consumption. During the first half of the 20th century, coal consumption grew less rapidly than total energy consumption because more convenient and competitively priced domestic oil and natural gas became available, and new uses of oil expanded rapidly. By 1950, coal dropped to 38 percent of the Nation's energy consumption, and the decline continued throughout the 1950's, 1960's and early 1970's. The advent of nuclear power, the elimination of oil import quotas beginning in 1966, and later in the early 1970's the implementation of the 1970 Clean Air Act, resulted in a further decline in coal utilization. By 1972, coal consumption was reduced to only 17 percent of total U.S. energy consumption. The actual volume of coal mined—as opposed to the percentage of total energy consumption—peaked first in 1945, reached a low level in 1960 of 435 million tons, rose thereafter and leveled off in 1970/71 at 525 million tons and since risen to 670 million tons in 1976.

Sectorial use of coal has changed since 1945. At that time the largest consumer of coal was the railroads, burning 125 million tons per year. Today, coal use by railroads is negligible. Retail consumption dropped from 19 million tons in 1945 to only 9 million tons in 1972. Industrial coal use declined from 148 to 72 million tons in the same 27 year period. Only demand in the electric utilities sector grew throughout the period, increasing from 72 million tons in 1945 to 349 million tons in 1972.[1]

The same trends have continued after 1972. The electric utilities consumed 446 million tons of coal in 1976, an increase of almost 35 million tons over the previous year and of almost 100 million tons over 1972. Coal demand from other sectors did not undergo much change: of the total 1976 increase in demand for bituminous coal and lignite of 41 million tons, only 8 million tons was from sectors other than electric utilities.

The high cost of oil, projected higher costs of oil and natural gas in the future, potential shortages of natural gas in the U.S., oil import

*Herman Franssen is a specialist in environmental policy at the Congressional Research Service.

[1] Federal Energy Administration, National Energy Outlook 1976, Washington, D.C., 1977, p. 165.

interruptions caused by war or political actions abroad, and government policy to discourage the use of oil and gas by electric utilities and some industrial uses, provide a bright future for the coal industry. Expansion of coal use in the United States is, however, subject to numerous constraints on demand and supply.

TABLE 10.—COAL CONSUMPTION BY SECTOR

[In million tons]

	Electric utilities	Metallurgical use	Industry	Residential/commercial	Exports
1945	72		148	119	
1965	245	95	104	22	52
1970	319	96	88	12	71
1971	326	93	74	11	57
1972	349	87	72	9	56
1973	387	94	67	8	53
1974	388	90	64	9	60
1975	403	82	64	7	66
1976	448	83	61	9	60
1985 [1]	715	73	151	5	80

[1] FEA projection in NEO 1976 (includes 1,600,000 tons for synthetics).

Source: Bureau of Mines.

Coal production has also undergone significant changes since 1945. Production has shifted from East to West and from deep to surface mining. In 1945, as much as 75 percent of U.S. coal production came from the Appalachian basin, 20 percent from the Interior basin, and 5 percent from the Far West. By 1972, Appalachian production had dropped to 65 percent, with Interior and Western production growing to 26 and 8 percent, respectively, of total production. Surface mining has increased from 19 percent in 1945 to 49 percent in 1972, and this new emphasis on surface mining occurred in every region of the country.[2]

TABLE 11.—COAL PRODUCTION [1]

[Million tons]

Year	East [2]			West			National total
	Surface	Deep	Total	Surface	Deep	Total	
1960	119	275	394	12	10	22	416
1970	221	328	549	34	10	54	603
1971	235	266	501	41	10	51	552
1972	236	294	530	55	10	65	595
1973	227	289	516	66	10	76	592
1974	245	267	512	80	11	91	603
1975	257	281	538	98	12	110	648
1976	251	279	530	122	13	135	665

[1] Excludes anthracite.
[2] East of the Mississippi River.

Source: Bureau of Mines.

A continuation of the shift in coal production expansion from Eastern to Western sources and from deep to surface mining, is projected in the 1976 National Energy Outlook (NEO). Of the 1,040 million tons of national production in 1985 (base case), 661 million tons (or 64%) is

[2] Ibid, p. 165.

projected to come from Eastern sources, and 379 million tons (or 36%) from Western sources. Surface mining is projected to grow from 373 million tons in 1976 to 655 million tons in 1985; deep mining is projected to produce 385 million tons in 1985, compared with 292 million tons in 1976

THE NATIONAL ENERGY PLAN

The National Energy Plan (NEP) holds that even with vigorous conservation measures, U.S. demand for energy will continue to grow. To avoid shortages and unacceptable oil imports, the U.S. will need increased domestic energy production. The authors of the NEP believe that for the remainder of the century the Nation will have to rely for the bulk of its energy supply on the conventional sources now at hand: oil, natural gas, coal, nuclear, and hydropower. The NEP authors call for a Federal policy to stimulate the expanded use of coal, supplemented by nuclear power and renewable resources, to fill the growing gap created by rising energy demand and relatively stable production of oil and gas.[3]

The Plan aims at reducing the use of oil and natural gas in the industrial sector (including electric utilities), by converting industry and facilities to the more abundant fuel, coal. Coal constitutes 90% of the Nation's conventional energy reserves, but supplies only 18% of energy consumption. The Plan aims at removing what it considers the principal constraint on coal utilization, lack of demand. To stimulate coal demand, the Plan proposes a coal conversion program consisting of taxes and regulatory measures. The tax measures are designed to raise the price of oil and gas to industrial users, and to provide incentives for conversion to coal. Industry would generally be eligible, at its election, for either an additional 10% investment tax credit for conversion expenditures or a rebate of any natural gas or petroleum taxes paid, up to the amount of any expenditures incurred for conversion to coal or other fuels. The regulatory part of the Plan would prohibit industry and utilities from burning natural gas and petroleum products in new boilers, with limited environmental and economic exceptions. Industrial firms could also be prohibited from burning gas or petroleum in new major fuel-burning installations other than boilers, by regulations applicable to categories of installations, or on a case-by-case basis (again subject to limited environmental and economic exceptions). Existing facilities with coal-burning capability could be prohibited from burning gas or oil, where the turning of substitute fuels would be economically feasible and environmentally acceptable. Facilities burning coal would be required to obtain a permit in order to shift to petroleum or gas. Utilities burning gas would require a permit to shift to petroleum instead of coal. By 1990, virtually no utility would be permitted to burn natural gas.

The effect of the Plan would be to increase the use of coal in 1985 by the equivalent of 2.4 million barrels of oil per day, or 200 million tons above the level projected without the Plan, and 6.4 million b/d (565 million tons) above the 1976 level.

---

[3] Executive Office of the President, Energy Policy and Planning, The National Energy Plan, Washinggon, D.C., 1977, p. 63.

TABLE 12.—NATIONAL ENERGY PLAN: COAL USE BY 1985

[In million barrels per day oil equivalent]

Sector	1985 Without the plan	1985 With the plan	1976
Industry	2.7	5.0	1.9
Electricity	8.2	8.3	4.9
Residential and commercial			.1
Total	10.9	13.3	6.9

Conversion Differences

The NEP document does not provide coal production figures other than the above quoted conversions in millions of barrels a day oil equivalent. The Bureau of Mines (BOM) figure for domestic utilization of coal in the U.S. is approximately 600 million tons, or 13.6 quadrillion Btu. The crude oil equivalent of 13.6 quadrillion Btu of coal is 6.4 million b/d. The NEP must have used a different conversion factor to arrive at 6.9 million b/d. The BOM in the 1976 edition of its annual report on U.S. energy demand and supply, used an energy conversion factor of 22.8 million Btu per ton of coal consumed in the U.S. in 1976. Assuming no change at all in the average Btu value of all coal consumed in the U.S. in 1985, the official BOM conversion factors would alter the coal use data in the NEP. The Plan calls for U.S. coal consumption of 1, 175 million tons in 1985 or 976 million tons without the Plan. At 22.8 million btu/ton of coal consumed, coal use in the U.S. in 1985 would be 26.8 quads with the Plan and 22.2 quads without the Plan. Converted to a crude oil equivalent, coal use in 1985 would be 12.6 milllon b/d with the Plan and 10.5 million b/d without the Plan.

NEP Coal Demand and Supply: A Comparison With NEO 1976

The NEP depends in part on projections in the NEO 1976 (PIES model), but assumptions changed regarding the mix of Eastern and Western coal as a percentage of total national coal production.

In the reference scenario of the NEO 1976, a large part of the increased production of coal would come from the Northern Great Plains (16 million tons in 1974 to 305.1 million tons in 1985) and Central Appalachia (from 184 million tons in 1974 to 297.3 million tons in 1985), the two major areas with low-sulfur coal reserves. Social, environmental and institutional problems would compound and are recognized as a limiting factor.

NEO 1976 also projects a significant increase in surface mine production; from 54% in 1974 to 63% in 1985. Surface mining is projected to almost double by 1985; deep mining is projected to grow by about 39% during that time. The increase in surface mining is largely a function of the substantially increased Western coal production from reserves which can be mined relatively cheaply, but only with surface mining techniques. Inexpensive Eastern strippable reserves are being depleted: hence the emphasis on Western strippable coal.[4]

[4] Federal Energy Agency, National Energy Outlook 1976, op. cit., p. 34.

TABLE 13.—COAL PRODUCTION BY REGION, 1985: A COMPARISON BETWEEN NATIONAL ENERGY OUTLOOK OF 1976 AND THE NATIONAL ENERGY PLAN OF 1977

[In millions of short tons]

Region	1974	1985: NEO, 1976: Low	1985: NEO, 1976: Base case	1985: NEO, 1976: High	1985: NEP, 1977: Without the plan	1985: NEP, 1977: With the plan
Northern Appalachia	171	174.9	182.6	201.9	189.0	257.4
Central Appalachia	184	287.0	297.3	305.9	319.3	348.5
Southern Appalachia	20	25.3	25.3	25.8	20.2	21.1
Midwest	135	175.2	155.8	190.4	177.0	203.4
Total, East	510	662.4	661.0	724.0	705.5	830.4
Central West	9	5.8	9.3	11.8	12.1	17.5
Gulf	8	16.8	20.6	25.3	56.5	63.1
Eastern Northern Great Plains	8	14.0	31.3	35.1	8.6	2.2
Western Northern Great Plains	8	234.9	273.9	402.6	220.2	225.6
Rockies	14	8.0	18.8	20.8	20.5	53.4
Southwest	14	15.0	20.6	28.9	35.8	65.0
Northwest	4	1.0	4.0	8.9	6.0	6.7
Alaska	1	.1	.1	.8	.8	.8
Total, West	93	295.6	378.5	534.2	360.3	434.3
Total, national	603	958.0	1,039.5	1,258.0	1,065.7	1,264.7
Exports	60	80.0	80.0	80.0	90.0	90.0
Domestic consumption:						
Rounded figure	551	880.0	961.0	1,183.0	976.0	1,175.0
In quadrillion Btu		19.1	20.6	24.9	21.9	26.4

The high coal utilization scenario in NEO 1976 calls for production of 1,258 million short tons, and a consumption of 1,183 million tons. To achieve this high volume, NEO 1976 projects that expansion will mainly have to come from the Northern Great Plains (1974 production of 43 million tons; 1985 high coal use scenario; 437.7 million tons). Total coal production from Appalachian and Midwest basins would only increase from 661 million tons in the base case, to 724 million tons in the high coal use scenario. The increase in the Western region occurs because it is the only region that has relatively inexpensive additional reserves to meet the greater demand for low-sulfur coal. Very significant potential socio-economic and environmental problems are foreseen if such action is taken.[5]

In a "Regional Limitation Scenario" which includes a 30% severance tax applied to all coal in the West, total coal production by 1985 is limited to 985 million tons, with much of the expansion in Eastern coal (from 510 million tons in 1974 to 662 million tons in 1985; Western coal would grow from 93 million tons in 1974 to 296 million tons in 1985).[6]

The NEP 1977 puts a great deal more emphasis on coal use as part of the total U.S. domestic energy supply than the base case scenario in the NEO 1976. In total projected 1985 volumes (in million short tons), the NEP is very close to the high coal use or electrification scenario in the 1976 NEO (see Table 13). There is, however, one considerable difference. The NEP requires that "best possible tech-

[5] Ibid, p. 35.
[6] Ibid, p. 35.

nology" be used in all facilities burning coal. Many experts agree that such a requirement will make Western coal use less competitive, and that subsequently demand for Eastern and Mid-western coal will rise because they are closer to the market.

The NEP projects Appalachian and Midwestern coal production to reach a volume of 830.4 million tons in 1985. The NEO 1976 projected Appalachian and Midwestern coal to contribute 724 million tons in 1985. Without the Plan, the Administration projected in 1977 that by 1985, Appalachian and Midwestern coal production would be 705.5 million tons. The NEO 1976 projected 661.0 million tons in its base case scenario.

The NEP projects Western coal to expand to 434.3 million tons by 1985. The NEO 1976 high coal use scenario projected 534.2 million tons for that part of the country. Without the Plan, the Administration projected in April 1977 that by 1985, Western coal production would reach a volume of 360.3 million tons. The NEO 1976 projected 378.5 million tons in its base case scenario.

The difference in total projected coal consumption converted from short tons into Btu's reflects the differences in regional distribution of coal supply in the NEP and NEO 1976. The NEP puts more emphasis on higher Btu Eastern coal, and therefore arrives at a higher total Btu figure by 1985 than the NEO 1976. The conversion factor used in the National Energy Plan is 22.5 million Btu/ton of coal; the conversion factor for the base case in NEO 1976 is 21.5 million Btu/ton, and for the high coal use case it is 21.0 million Btu/ton (higher mix of Western low-Btu coal than in the base case).

The NEP also differs slightly from the NEO 1976 in projecting surface and deep coal mining activities through 1985.

TABLE 14.—PRODUCTION BY TYPE OF MINING, 1985

[Million tons]

	Surface	Deep	Total	Surface as percent of total
1974:				
East	244.8	266.7	511.5	47.9
West	81.3	10.6	91.9	88.5
National	326.1	277.3	603.4	54.0
1985 (base case, NEO 1976):				
East	292.8	368.2	661.0	44.3
West	362.2	16.3	387.5	95.7
National	627.2	438.6	1,039.5	63.0
1985 (base case, without NEP 1977):				
East	283.0	422.5	705.5	40.0
West	344.2	16.1	360.3	95.0
National	627.2	438.6	1,065.8	(?)
1985 (NEP):				
East	292.0	538.0	830.0	[1] 35.0
West	372.0	62.0	434.0	86.0
National	664.0	600.0	1,264.0	53.0

[1] Rounded figure.

Future U.S. Coal Production and Utilization: A Comparative Analysis

Following the Arab oil embargo of 1973/74, the newly created Federal Energy Administration (FEA) embarked on a major study to determine whether and when the United States could reduce its dependence on imported oil. In November, 1974, the Project Independence blueprint was published. It projected that coal production in the United States could reach between 754.9 and 926.5 million tons per year as early as 1977 (base case and accelerated case). The short-term production forecast for 1977 in the NEO 1976 was more pessimistic. It projected a total U.S. coal production in 1977 of 715 million tons. The most recent information from FEA and BOM indicates that actual U.S. coal production in 1977 is more likely to be similar to—if not slightly less than—the 1976 production of 671 million tons. Hence, compared with the Project Independence and NEO forecasts, coal production in 1977 is likely to be between 44 and 84 million tons below the 1976 and 1974 FEA base case forecasts. The Project Independence accelerated scenario for 1977 is not likely to be achieved until the early 1980's, or, according to some forecasts, the middle 1980's.

Domestic oil and natural gas production declines, the Federal Power Commission (FPC) policy to allocate natural gas away from electric utilities, the fear of another disruption of imported oil, and the high cost of oil have all caused many consumers to explore ways to substitute coal for oil and gas. Moreover, the operating cost of nuclear power plants and a number of other concerns related to the nuclear fuel cycle have already led to numerous cancellations of projected nuclear power plants since 1974. The uncertainty of the nuclear power option, coupled with the high cost and uncertainty of supply of oil and natural gas, have made the coal option for electrical power generation increasingly interesting to electric utilities.

The FEA, under the Energy Supply and Environmental Coordination Act (ESECA) of 1974, has attempted to convert many power plants from oil and gas to coal, but the agency has met with little success. Few power plants have actually converted to coal, and construction orders to build coal-fired power plants were not needed, because the utilities were already planning to build them. ESECA has been extended twice and strengthened to permit FEA to order new power plants and major fuel burning installations (MFBI) to burn coal. The National Energy Plan would replace ESECA with a new regulatory program in which oil and gas use in utility boilers would be prohibited. Temporary exemptions could be granted under certain conditions, but the burden of proof would be on the boiler operator rather than on the government as is the case under ESECA. The NEP's oil and gas use taxes and a proposed mechanism to rebate the the tax to boiler operators converting to coal, are designed to ease the financial burden of new coal-related investments.

This chapter will not discuss the costs of the proposed shift from oil and gas to coal, but will only address the effects of that shift on coal demand and supply, and examine whether the projected domestic coal utilization figure of 1,175 million tons by 1985 is likely to be achieved (total production is estimated at 1,265 million tons).

GAO Evaluation of NEP Coal Use

The General Accounting Office (GAO) does not believe that the NEP coal use figure of 1,175 million tons and production of 1,265 million tons will be achieved by 1985. The GAO doubts that even the base case without the Plan—1 billion tons by 1985—is likely to be achieved. GAO maintains that the expanded use of coal even to 1 billion tons in 1985 will not take place if all air quality regulations are strictly enforced. Less costly and reliable technology to control pollution is needed, according to GAO. Without it, GAO believes, a significant increase in coal use will lead to further environmental degradation, despite the strong pollution control measures in the plan. In the longer term, assuming an aggressive and successful coal R & D program, the need trade-offs may be substantially diminished.

GAO lists a number of other constraints on higher coal use. The most important of these are: the state of the railroads required to transport the coal to where it will be burned; the unresolved problem of coal slurry pipelines; poor labor relations; manpower and training requirements, in particular for deep mining; health and safety regulations; and, gradually eroding labor productivity since 1969. GAO maintains that the NEP does little to solve these problems, which are likely to hinder achievement of the coal use targets set in the Plan.

While GAO doubts that a coal use target of 1 billion tons can be achieved, reaching it would still be 2 million tons or 2.4 million b/d oil equivalent below the level projected in the NEP.

OTA Evaluation of NEP Coal Use

The analysis of NEP's coal use projections by the Office of Technology Assessment (OTA) is in general agreement with the evaluation by GAO.

OTA maintains that the levels of supply projected by the Plan represent the upper limits of capacity, and supplies of all fuels are likely to fall below the Plan's goals. There is little—if any—margin of error in the production schedules of the NEP.

OTA estimates that coal production could fall short by as much as 200 million tons (or 2.4 million b/d oil equivalent) because of the following constraints: (*a*) manpower and capital shortages could delay opening of new underground coal mines; (*b*) additional coal production facilities will be constructed by the coal industry only if new markets for coal are assured, which may require some short-term trade-offs between environmental objectives and production targets, since the new boilers and pollution control devices may not be available for the rapid conversion to coal use; (*c*) transportation bottlenecks could prevent coal from being delivered where it can be used, particularly in the East; and (*d*) strip mining legislation may foreclose development of large reserves in the West where leases already have been signed and long-range mining plans have been completed, hindering production of Western coal.

The timing factor and environmental trade-offs are very important. OTA maintains that hundreds of industries must reactivate coal-burning facilities or buy new equipment before the demand for coal will expand. The high cost of equipment and inability to meet demand for boilers and pollution-control equipment, could retard growth in

the demand for coal. Delays in demand growth will in turn affect expansion of future supply.

The OTA report also states that the Plan fails to acknowledge that there will be inevitable conflicts between environmental protection and increased energy production and use, and recommends that the Administration should face that possibility squarely and propose mechanisms for resolving the conflicts. OTA suggests that if energy production falls short of the Plan's forecast, it is more likely to be caused by environmental and regulatory conflicts than by the lack of available resources, capital or manpower.

The Plan, according to OTA, provides no direct incentives for new coal production, but relies entirely on creating higher demand. OTA is worried that the Plan does not contain any contingency plans for stimulating production of energy or further reducing consumption in the event of slippage in one or more sources.

GAO, U.S. COAL DEVELOPMENT—PROMISES, UNCERTAINTIES (1977)

This report was published on September 22, 1977; too late for a careful analysis in the present study. However, the GAO report makes an important contribution to our knowledge, and some general observations from the study deserve to be quoted.

GAO points out that while coal reserves are vast—estimates of BOM identified 250 billion tons—they are by no means unlimited. At the BOM rate of goal consumption of 1,586 million tons, identified reserves would last about 74 years. The BOM demand forecast is by no means the highest (see Table 16). When coal prices increase, mineable reserves are likely to increase and extend the life of U.S. coal reserves.

The distribution of reserves is important, particularly because much of the low-sulfur coal is located in the West, far removed from the major markets. The sulfur content of coal is of great importance because of the provisions in the Clean Air Act, limiting consumers to using coal with a low-sulfur content. About 89% of all coal in the Nation that, according to BOM estimates, can be used for direct combustion and meet Clean Air Act standards is located in the West.

On domestic supply and demand of coal, the most important conclusions of the GAO report are summarized in the report as follows:

> * * * We have doubts about the possibility of achieving the administration's plan of producing and using 1.2 billion tons of coal by 1985 or, for that matter, even the level of one billion tons the administration assumes will be achieved without its plan. Given all the physical, economic, environmental, and public health considerations, it appears that producing and using even a billion tons by 1985 will be difficult. Assuming, however, that the difference is 200 million tons, the shortfall on the domestic energy supply side in terms of oil equivalent would be 2.3 million barrels per day. In addition, GAO does not agree with the administration's formula for computing the oil equivalents of coal. The magnitude in the difference in the administration's calculations as compared to GAO calculations, as far as coal is concerned, is about 1.1 million barrels of oil equivalent per day * * *.

GAO did not undertake a quantitative analysis of U.S. coal supply and domestic demand, but instead compared what it considered a high supply estimate by BOM with a low estimate of the Edison

21-616—78——5

Electric Institute. The scenarios ranged from a low total demand figure of 779 to a high of 988 million tons by 1985, and from 942 to 1,586 million tons by the year 2000.

The GAO report indicated that discussions with 11 major coal producers showed that all believed that U.S. coal production could be doubled by 1985, but GAO believed that a number of factors, including long lead times required to open mines, environmental constraints, delivery times of heavy equipment, capital problems, labor and productivity problems will delay beyond 1985 the achievement of a production level of 1 billion tons, let alone the 1.2 billion tons reflected in the National Energy Plan. GAO agrees that a production level of 1.5 billion tons can be achieved by the year 2000.

Other constraints on achieving a 1985 production level of 1 billion tons are according to GAO:

The 1969 Federal Coal Mines Health and Safety Act which increased the number of personnel in the mines, and lowered productivity;

Changes in mining conditions such as width of coal seams, distance from entrances of mines to the operation faces, and amount of overburden;

Introduction of large numbers of inexperienced workers into the mines;

Requirements for additional personnel in accordance with union agreements;

Unscheduled interruption in production caused by wildcat strikes.

Capital availability is to a large extent dependent on firm demand for coal. The recent trend toward fewer and larger companies may ease capital problems. Manpower, but in particular trained manpower, is a significant problem, which deserves more attention. Most mining equipment should be available if there is adequate planning by the industry. Large draglines for surface mining may be in short supply. OSHA has improved health and safety standards, but the GAO report still projects a large increase in total number of dead and disabled mineworkers as a result of production expansion. In some States, State taxes on coal mining may reduce production, but State taxes have the advantage of internalizing external socio-economic and environmental costs.

GAO believes that transportation problems related to increased coal production can be solved, but Federal action may be needed. The study agrees that in the West, increased traffic, noise and air pollution are trade-offs for increased coal production.

GAO estimates that environmental costs associated with increased coal production—the degradation of the environment—are perhaps the most important of all costs. GAO estimates capital costs for emission control to be about $19.1 billion in 1985 and $26.4 billion by the year 2000. This could add an additional 9 to 10 percent to the average residential consumer's electric bill. Many regard this as a reasonable price to pay in exchange for a guaranteed fuel supply. Disposing of the sludge collected in pollution control devices such as scrubbers is likely to be a problem. The volume of sludge generated annually by 1985 is estimated to be equal to the municipal waste generated in the U.S. during the course of one year. The GAO study points out that with best-available-technology in use today, a great many pollutants

dangerous to human health or harmful to plant and animal life, cannot be prevented from escaping in the atmosphere. Moreover, the carbon dioxide build-up (CO_2 cannot be controlled with current scrubber technology) may have adverse effects on climatic conditions during the next 50 years.

Other environmental problems related to coal production cited in the GAO study are: acid mine drainage, land subsidence, denuded lands, soil erosion, and sedimentation. In the Western part of the U.S., coal development may adversely affect the hydrology of certain regions. One question that will arise in such cases is related to the transfer of water rights from existing use to coal production and conversion.

Socio-economic problems are similar to those felt in the coastal zone whenever major offshore oil and gas developments take place, or when new large mining developments are undertaken in new areas. Infrastructural costs in local communities rise rapidly due to the influx of people, and these high front-end costs may be beyond the immediate capability of many communities. Some States have enacted legislation intended to mitigate those costs, and limited Federal assistance is available. Other social problems are related to those felt in "boom towns" such as Fairbanks, Alaska. Increased rates of inflation, services breaking down, crime rate increases, prostitution, alcoholism, and other vices tend to increase rapidly in previously quiet communities.

A number of other recent studies have projected coal use in the United States, and while few of these studies are a response to the National Energy Plan, all show the promises and constraints associated with higher coal use in the United States.

CONGRESSIONAL RESEARCH SERVICE, PROJECT INTERDEPENDENCE: U.S. AND WORLD ENERGY OUTLOOK THROUGH 1990 (JUNE 1977)

The CRS study made much the same comment as the recent GAO report on revised coal reserve estimates, indicating that coal reserves are indeed vast, but at projected rates of growth of production, reserves would not last much more than a century (still very large, but not as large as projected in most earlier studies).

CRS projected the following coal use scenario for the next fifteen years:

TABLE 15.—U.S. PRODUCTION AND UTILIZATION OF BITUMINOUS COAL AND LIGNITE

	Million tons		Quadrillion Btu	
	Domestic utilization	Exports	Domestic utilization	Exports
Low:				
1977	610	65	13.2	1.7
1980	640	80	13.2	2.1
1985	760	90	14.9	2.4
1990	1,020	90	19.9	2.4
Median:				
1977	630	65	14.0	1.7
1980	695	80	14.3	2.1
1985	850	90	16.3	2.4
1990	1,135	90	22.2	2.4
High:				
1977	660	65	14.4	1.7
1980	730	80	15.1	2.1
1985	940	90	18.5	2.4
1990	1,250	90	24.5	2.4

In the CRS forecast, coal production measured in short tons will increase more rapidly than that measured in Btu's. This is due to the fact that, using BOM's data, the average Btu content of coal is projected to decrease when the percentage of low-Btu Western coal increases as a percentage of total production. Estimated Btu's per short ton of product in the CRS report were 11,100 in 1977; 10,600 in 1980; 10,100 in 1985; and 10,000 in 1990. Average Btu content of domestically used coal by 1980, 1985, and 1990 would be lower, because exported coal consists almost exclusively of high-Btu metallurgical coal.

In its base case, CRS projected medium coal use of 850 million short tons and exports of 90 million tons, but domestic coal use could be as low as 760 million tons or as high as 940 million tons.

The CRS forecast is a qualitative estimate based on demand and supply projections taking into account the following constraints: environmental enhancement efforts, their kinds, severity and rigor, timing and capital requirements; trained manpower and labor productivity; transportation facilities; Federal leases; demand uncertainty caused by environmental restrictions; labor problems; water problems in the West; and, potential shortages of equipment.

ALLEN F. AGNEW, COAL, CARTER, AND CONSTRAINTS (CRS, 1977)

Dr. Agnew (senior specialist at the CRS) maintains that U.S. demand for coal will probably not be satisfied in the quantities and at the times needed, because much of it has low heat value, and because of a number of other constraints—such as environmental restrictions, unavailability of capital, inadequate transportation network, labor problems and low worker productivity, delays in access to the huge coal reserves on public lands in the West, and other factors such as unexpected weather conditions—unless a number of costly actions are taken by the Congress and the Administration to lessen their effect.

Without such measures, according to Agnew, it would seem that President Carter's goal of increasing coal production to more than 1.1 billion tons by 1985, although salutary, is not likely to be attained. Rather, coal production in 1985 may fall perhaps 100 million tons or more short of that goal. A mix of demand and supply constraints on coal use will limit coal use targets set by the government. Agnew lists the following constraints: (*a*) environment; (*b*) workers and productivity; (*c*) transportation; (*d*) capital availability; and, (*e*) access to Federal coal.

Many of these issues are interrelated, which makes a piecemeal approach to solving the problems difficult.

Environmental regulations, together with uncertainties concerning their degree, cost, and rigor of enforcement, constitute a rather important set of constraints. The surface mining law of 1977 is likely to remove a substantial factor of uncertainty, but the degree of inhibition to current and proposed mining will probably be difficult to assess for some years to come. Future EPA action against violators of the Clean Air Act are also not easy to project, because the EPA has granted numerous variances in the recent past. This and nonenforcement have together resulted in a situation whereby quantities of coal being burned that are not in compliance with the law are very high. But, will

EPA continue this policy in the future for new power plants in view of the fact that the electric power industry maintains that the technology to build highly reliable sulfur-dioxide removal systems is not expected to be fully developed for several years?

On worker productivity, Dr. Agnew quotes BOM's statistics showing a one-third drop in coal mining productivity since 1969. The drop in productivity is said to be primarily caused by attempts of operators to comply with the requirements of the Coal Mine Health and Safety Act of 1969. FEA in its Project Independence study projected increasing growth in productivity to meet the 1985 production target of 1.1 billion tons of coal. But, FEA projections to the contrary, labor productivity has continued to drop since the publication of the study. Labor-management relations and availability of trained labor, in particular for deep coal mining, also count among the major constraints on coal production.

While the railroads maintain that by 1985 they can handle twice as much coal as they transport today, availability of larger rail cars and the capability of tracks to withstand the heavier loads caused by larger cars, may not be counted on. Moreover, the enormous increase in rail and truck traffic needed to move the increased coal produced, is likely to meet public opposition. Coal slurry pipelines may be constrained by water use issues and by the lack of eminent domain required to cross railroad right-of-way. Timely availability of capital to open up new coal mines is also questioned by Dr. Agnew. Finally, it is feared that access to Federal coal (85 percent of the Nation's low-sulfur coal and 70 percent of its strippable coal) is likely to be delayed by Federal regulations, despite the removal of several roadblocks to the resumption of the Federal coal-leasing program.

Dr. Agnew projected three coal use scenarios for 1985 and 1990 for the Project Interdependence study (see Table 16). He believes that the low production numbers (850 million tons in 1985 and 1,150 million tons in 1990) seem most likely to be achieved without costly and complex governmental intervention on a scale with little precedent in the United States.

EXXON, ENERGY OUTLOOK, 1977–1990

Exxon projected coal supply in the United States to increase to 709 million short tons in 1977, 814 million tons in 1980, and 1,070 and 1,477 tons, respectively, in 1985 and 1990. The largest growth was projected for the Western States, where production would increase from 110 million tons in 1975 to 142 million tons in 1977, 195 million tons in 1980, 340 in 1985 and 597 million tons in 1990. Exports of primarily metallurgical coal were estimated to remain at about 60 million tons through 1980, rising to 95 million tons annually by 1990.

Eastern coal production was projected to expand at a rate of 3.4 percent annually between 1977 and 1990; Western coal output would expand at a rate of 11.7 percent per year. Most of the future production from the East would come from deep mining. Higher costs of mining were said to be somewhat offset by the fact that Eastern coal production is close to established markets and existing transportation systems.

The Exxon study, which was made prior to the publication of the NEP, estimated that much of the expanded production must come from Western fields as a result of environmental regulations requiring low-sulfur fuels. In total, Western coal is projected to increase from 20 percent of U.S. coal production in 1977 to 40 percent by 1990.

About 82 million tons of coal per year was estimated to be used for producing gas and liquids from coal by 1990.

GERALD C. GAMBS, ENERGY OUTLOOK—ALTERNATIVE FUELS AND CONVERSION OUTLOOK

Coal industry spokesmen generally agree that the National Energy Plan's supply projections of 1.265 million short tons by 1985 can be achieved, but most industrial sources also maintain that several of the constraints mentioned elsewhere will have to be removed. Non-official supply estimates from analysts in the coal industry tend to be lower than official projections, and range between 1 billion and 1.1 billion tons (including about 75 million tons of metallurgical coal for the export market).

One outspoken critic of the high coal use estimates by industry and some government agencies is Gerald Gambs, vice-president of Ford, Bacon & Davis in New York. Gambs has taken a careful look at the constraints on coal use, and has concluded that without removal of those constraints the Nation is not likely to produce more coal than between 774 and 853 million short tons by 1985.

Gambs maintains that it will be impossible for U.S. coal production to reach the NEP's projected level of 1,265 million tons by 1985. It would require a total of 750 million tons of new mine capacity between 1977 and 1985 (including 150 million tons to offset depletion). This would mean that in the next eight years we would have to add 94 million tons of new capacity every year. This is about ten times the new capacity added each year during the past twenty years.[7]

Gambs hold the view that if we exerted a superhuman effort and we removed all the roadblocks ahd obstacles to developing all the new coal mines which we would need, we would probably still fall short of 1 billion tons per year by 1985.[8]

Coal reserves in the U.S. are such that coal could contribute between 20 and 25 percent of total U.S. energy supply for the near and intermediate term. Gambs listed the same constraints on coal use discussed earlier elsewhere in this chapter, and maintained that these constraints will keep coal use below 1 billion tons per year by 1985.

Even a coal production of 1 billion tons per year would require new capacity of 515 million tons by 1985 (including 150 million tons for depletion). Assuming that 300 million tons will be Western coal, this will require 60 new 5 million tons per year mines in the Western States. The balance of 215 million tons could be obtained by developing 80 new 2 million tons per year underground mines and 28 new 2 million tons per year surface mines in the East. This schedule calls for constructing 168 new large mines in the next 8 years, to 1985. In 1976, there were only 22 coal mines with a production capacity of 2 million tons or more which had started up since 1965, and only two of these

---

[7] Gerald C. Gambs, Energy Outlook Alternative Fuels and Conversion Issues, New York, 1977.

[8] Ibid, p. 22.

produce more than 5 million tons per year. Comparing the projected additions to mining capacity for the next ten years (to reach a production of 1 billion tons) with the experience of the past ten years, provides a measure of the huge effort required.

While Gambs is known to be pessimistic about coal use under current Federal and State regulations, his analysis provides an interesting comparison with the National Energy Plan, which is generally considered to be overly optimistic in its coal use projections. The NEP is likely to have overlooked many of the serious constraints on coal demand and supply in the U.S. for the next decade.

INSTITUTE FOR ENERGY ANALYSIS, OAK RIDGE ASSOCIATED UNIVERSITIES, OUTLOOK FOR THE COAL INDUSTRY IN THE UNITED STATES (1977)

This study foresees a bright long-term, but modest short-term future for coal. Almost all regions in the United States are expected to add coal-burning facilities. The study, which was completed prior to the release of the National Energy Plan, is an economic analysis which compares the use of low-cost, low-sulfur coal in the West with nuclear power. The requirement in NEP to use best-available-technology is likely to change the cost-benefit analysis of coal.

The study agrees with most other studies compared in this chapter, in that most of the uncertainty with respect to coal's future up the end of the century seems to rest on the demand side rather than on the supply side. It differs with several of these studies by minimizing the potential effects of capital and manpower shortages on supply. The outcome of the coal-nuclear cost and environmental impact controversy, and the rate of substitution of readily available coal for less available natural gas for utilities and industrial boilers, are listed as the key issues affecting future coal use.

Utilities are the largest potential market for coal, and the impact of stiff environmental standards has led to some replacement of existing coal-burning plants (as in New England), and a reluctance to build new ones. Utilities must be convinced that they can burn higher sulfur coals without violating environmental standards; this will require effective technological improvements (such as fluidized beds) to keep coal-fired plants in a competitive position with nuclear plants in regions where low-sulfur coal is not a practical alternative.

The passage of air-pollution control regulations by States, later accelerated by the passage of the Federal Air Quality Act in 1967 and the Clean Air Act in 1970, adversely affected utility planning for coal use in the future. As a boiler fuel, oil produces far less nitrogen oxide and particulates than does coal. The Clean Air Act requires conformance to State regulations for six potential pollutants: sulfur dioxide, particulates, nitrogen oxides, carbon monoxide, hydrocarbons, and photochemicals oxidants. Sulfur dioxide is the most important for coal burning. Many State Implementation Plans set the permissible sulfur content of emissions at levels far more stringent than would be needed to comply with Federal standards. This condition has made compliance difficult because of supply shortages and the higher prices of low sulfur coal. Notwithstanding some easing of air pollution regulations, in fiscal year 1975 nearly half (49 percent) of the coal

burned by utilities and other consumers did not conform to emission requirements. More stringent enforcement of environmental standards can be expected in the future. The Oak Ridge study is fully aware of the problems associated with nuclear power plant developments. In spite of this, the study concluded that if technological developments are not forthcoming to overcome the environmental drawbacks to coal burning, then decisions to rely more heavily on nuclear plants are almost a certainty. (p. 31).

The study was concerned about the drop in productivity in coal mining since 1969 (about 30 percent in underground mines), and wondered if the present period is one of readjustment only, to be followed by a resumption of the long-term rising trend in productivity.

Reclamation policy was said to be a serious problem in some surface mining areas in Appalachia, where reclamation costs could be up to fifteen times higher than average reclamation costs in the West.

Leasing of Federal lands for coal production in the West, where the government influences up to 80 percent of development, was also considered very important to meet future production goals. While production of Western coal has increased rapidly, only 5 percent of federally-owned coal resources were under lease by 1974. A policy of delay and indecisiveness can retard, if it has not already done so, the availability of low-cost, low-sulfur coal, according to the IEA study. The resumption of leasing is a favorable development says IEA, but long delays are currently being experienced before final approval is received, partially due to stiff environmental impact requirements. Therefore, the IEA study concludes, coal supply availabilities are retarded.

The Oak Ridge study quoted a BOM survey of 1976, which indicated that the industry plans to open new mines or expand existing mines with a total and final capacity of about 715 million tons. Two-thirds of the total—472 million tons—is planned to originate in Western coal fields. In view of the higher depletion rate in the East, the IEA study considers the planned expansion of output in the East—243 million tons—rather low. However, the planned expansion did agree with planned expansion of coal-fired power plants in the East at that time. NEP's emphasis of Eastern over Western coal and the coal conversion program could change those expansion plans.

The IEA forecasts a 2 to 3 percent annual growth rate in domestic demand for coal in the United States. Assuming a similar growth rate for the export market, 1985 coal production would be between 775 and 850 million tons. The study projects a maximum domestic demand for coal of 1,370 million tons by the year 2000. Assuming coal exports of about 100 million tons in that year, the IEA analysis for the year 2000 is close to quoted GAO estimates for that year. The IEA coal use data for 1985 are similar to those projected by Gerald Gambs, and the IEA high coal use scenario lies between the high and low cases of GAO.

The study anticipated that most of the growth will take place in the Western States, which will raise the proportion of low-sulfur coal mined. The study estimated price increases averaging 2 percent per year in constant 1975 dollars. The forecast of modest price and production increases would be raised significantly if the States were to opt for a moratorium on the construction of nuclear-powered generating plants.

Compared to 1976 output of 665 million tons, the average of the two IEA projected domestic consumption trends (high and low) would represent an increase of 410 million tons, with a maximum growth of 705 million tons by 2000. This would be a compound annual growth rate of 2 to 3 percent, not very different from the moderate expansion of actual production from 1975 to 1976.

CONCLUSIONS

On the basis of the studies analyzed in this chapter, the following conclusions may be drawn:

Coal reserves in the United States are adequate to meet projected expansion of demand for at least 75 to 150 years (depending on the growth rate of demand and actual reserve estimates).

There are substantial differences in coal demand and supply projections in the studies analyzed here. The three congressional research centers—CRS, GAO, and OTA tend to agree that production of coal is likely to be below the one billion ton mark in 1985; the Administration projects U.S. coal production to reach 1.2 billion tons by 1985. All of the various studies discussed in this chapter do not differ very much on coal use projections for 1990 and the year 2000.

Most studies have reached the conclusion that uncertainty with respect to the future use of coal, at least initially, rests on the demand side of the equation. Environmental and regulatory policies are likely to limit coal demand. The high cost of coal conversion and the inability of industry to meet potential demand for boilers and pollution control equipment, could also retard demand for coal.

Without assured markets, the coal industry is not likely to expand production capacity significantly. The following constraints are likely to have an adverse affect on future coal supply: inadequate transportation systems; manpower, and especially trained manpower; declining productivity, in part caused by government regulations; labor-management relations and trade union problems; potential equipment shortages; certain strip-mining regulations, in particular in Appalachia; potential capital formation problems; institutional problems, in particular in Western States; and, environmental and water use problems.

Most studies project the need for very substantial expansion of Western coal production to achieve a 1985 total coal production level of one billion short tons. The percentage of Western coal, which can be strip-mined, may have to increase from 15% of total production in 1974 to between 35% and 40% of total production by 1985. The projected shift in production expansion from high-Btu Eastern to lower-Btu Western coal will require a much larger volume of coal production (calculated in short tons) than the current mix of Eastern and Western coal output in order to arrive at the desired demand in Btu s (heat value of coal expressed in British thermal units).

The following probable and possible coal use scenarios are based on a qualitative analysis of the studies discussed in this chapter.

TABLE 16.—PROBABLE AND POSSIBLE COAL USE ESTIMATES FOR 1985

[In million short tons and quadrillion Btu]

Probable			Possible		
Sector	Million short tons	Quads [1]	Sector	Million short tons	Quads
Electric utilities	700	14.7	Electric utilities	776	16.3
Industrial uses	160	4.2	Industrial uses	180	4.7
Other uses	5	.1	Other uses	9	.2
Total, domestic coal use	855	19.0	Total, domestic coal use	965	21.2
Coal exports	75		Coal exports	75	
Total, coal production	930		Total, coal production	1,040	

[1] Conversion factors: Coal for electric utilities 1985: 21,000,000 Btu/ton (21,600,000 Btu/ton in 1976). Industrial and other uses 1985: 26,300,000 Btu/ton in 1976. Changes in Btu/ton for steam coal represent a shift from the current mix of east/west coal for electric utility use to more imphasis on lower-Btu western coal.

TABLE 17.—COMPARISON OF U.S. COAL PRODUCTION ESTIMATES

[Million tons]

Study	1980	1985	1990	2000
Federal Energy Agency: Project Independence (1974):				
Business as usual	895	1,100	1,300	
Accelerated case	1,376	2,063	2,803	
FEA, National Energy Outlook (1976):				
Base case ($13 oil)	799	1,040	1,307	
Electrification scenario		1,258		
National energy plan (1977)		1,265		
Congressional Research Service (1977):				
Project Interdependence, base case	775	940	1,225	
Project Interdependence, high supply	810	1,030	1,340	
International Energy Agency/OECD (1977): Reference case	799	1,039		
Exxon (1977)	814	1,070	1,477	
MIT/WAES (1977):				
C case (hoped for future)		950		(C1) 2,009
A case (highest)		1,040		(C2) 1,452
D case (lowest)		800		(D8) 1,104
General Accounting Office (1977):				
Low coal use scenario		799		1,500
High coal use scenario		998		
Office of Technology Assessment (U.S. Congress): Probably coal use		<1,000		
Bureau of Mines (1976)	806	998		1,660
Gerald Gambs (Ford, Bacon & Davis) (with current constraints)	735	853		
Institute for Energy Analysis (Oak Ridge):				
Low coal use case—2 percent annual increase		775		[1] 1,370
High coal use case—3 percent annual increase		850		

[1] Excluding exports.

The Supply of Nuclear Power in the United States

(By Warren H. Donnelly*)

PURPOSE

For some people and organizations, especially those dedicated to protection of the environment and gravely concerned with what they see as the excesses of present U.S. society, the future use of nuclear power is abhorrent, excessively dangerous to health, safety and national security, and likely to cause unacceptable curtailment of civil liberties. For others, especially those connected with the nuclear power and electricity industries, the future use of nuclear power is necessary and desirable to relieve dependence upon imported fuels, to reduce the environmental effects of burning coal to generate electricity, and as an economical source of power. It is not evident that the majority of citizens are wholly convinced one way or the other. Nonetheless, continuing and, in some places, growing, opposition to nuclear power has kept questions about the future of nuclear energy continually before Congress.

The future supply of electricity from nuclear energy is an important consideration in national energy policy. Government action to increase nuclear power would bring some benefits and attendant costs. Government action to decrease its use would reduce some risks but bring some undesirable consequences. The purpose of this section is to sketch briefly the history of nuclear power in the United States; summarize the present situation; present forecasts, with reasons for uncertainty in these forecasts; and outline constraints upon its future supply. Several landmark analyses of nuclear power are also examined as is the role assigned to nuclear power in the President's national energy plan.

PART I. BACKGROUND

Overview

The use of nuclear power is technologically feasible. Nuclear power is now in commercial use throughout the world. Many nuclear powerplants are operating in the United States, more are under construction and still more are on order. On the other hand, continuing controversy clouds the future supply of nuclear power. At issue are the economics of nuclear power and the risks which some critics perceive to the public health and safety, environment, national security and world peace. The United States possesses the world's largest industrial base for civil use of nuclear power, but several parts necessary for the continued or expanded long-term use of nuclear power are still missing. Since proposals to impose a national moratorium upon nuclear power have yet to succeed, it appears that the principal policy questions for the future supply of nuclear power are how much more nuclear gen-

---

*Warren H. Donnelly is a senior specialist in energy policy at the Congressional Research Service.

erating capacity should be provided, if any, where, and when. Experience with forecasts for future nuclear power during the past 15 years strongly indicates they are unreliable as the basis for future public and private decisions about additional nuclear powerplants. The existing U.S. nuclear powerplant industry is underemployed because of a fall-off in new orders over recent years and may face consolidation, or exit by some manufacturers if the market does not improve. The availability of uranium to provide nuclear fuel for nuclear power plants while probably sufficient to support those now in operation, being built, or on order, may not be sufficient to fuel substantial additional expansion if present type nuclear powerplants are used. The further development and demonstration of nuclear powerplants capable of producing much more electricity per pound of uranium has become intensely controversial and President Carter has laid down policies to postpone indefinitely one type of powerplant—the plutonium breeder reactor—until certain criteria can be met. Meanwhile, other technological options to get more kilowatt-hours of electricity per pound of uranium are to be intensively reexamined.

History and background

Since the discovery of nuclear fission in uranium in 1939, and especially since government research and development for nuclear power began to expand in the early 1950s, it has been expected that nuclear power would furnish an increasing part of the expanding supply of electricity forecast for the United States. Since the 1960s, however, critics increasingly have questioned what they perceived to be the risks of nuclear energy to the public health and safety, to the environment, to the rate payer, and to national security and world peace.

The first nuclear powerplant to be operated by a public utility in the United States was the Shippingport Atomic Power Station, in Pennsylvania, which achieved its initial design power output in December 1957. The first commercially designed and built nuclear powerplant, the Dresden Unit 1 of the Commonwealth Edison Company in Illinois, achieved initial design power in June 1960 and went into commercial operation in August of that year.

Research and development for nuclear power by the U.S. Atomic Energy Commission (AEC) in its early days led to the testing and demonstration of several types of nuclear power reactors, with the nuclear power industry finally settling upon two types, the pressurized water reactor which is manufactured by three U.S. companies, and the boiling water reactor, which is made by a fourth. Another type, the high temperature gas cooled reactor, was privately developed but failed to attract buyers and is no longer available in the U.S. market. The two types of commercial reactors now used in the United States are known as light water reactors (LWRs) because of their use of normal water both as a coolant to carry the heat energy out of the reactor for conversion into electrical energy, and as a moderator for the nuclear reaction.[1]

For more than the past decade, Federal research and development for nuclear power has focused on one particular breeder reactor system,

---

[1] In light water reactors, the function of the moderator is to slow down the neutrons that are emitted by fissioning atoms of uranium-235 enough to maximize the probability that they will be able to cause another atom of U-235 to fission in a chain reacting system. Graphite can also be used as a moderator, as is the case for some nuclear power reactors in the United Kingdom and in the Soviet Union. "Light water" is specified because in another type reactor, developed in Canada, heavy water or deuterium is used as the moderator.

the liquid metal, fast breeder reactor (LMFBR). In April 1977, President Carter announced his decision to redirect the LMFBR program of the Energy Research and Development Administration (ERDA) and to cancel construction of a demonstration LMFBR at Clinch River in Tennessee. This type of breeder reactor would produce heat for generation of electricity, and also convert enough non-fissionable uranium (uranium-238) into fissionable plutonium to more than offset nuclear fuel consumed in its operation. Since most of the uranium found in nature is U–238 (some 99.3 percent), the idea of transforming this U–238 into useful nuclear fuel has intrigued scientists and engineers since development of the atom bomb during World War II. Unfortunately for the advocates of nuclear power, plutonium can be used to make weapons, even in the somewhat contaminated form produced in breeder reactor operation.[2]

The President's nuclear policy decisions also would prevent the reprocessing of spent fuel from commercial light water reactors to recover residual plutonium, and the use, or recycling, of that plutonium as fuel in other reactors.

The present state of nuclear power

During 1976, U.S. nuclear powerplants produced 191 billion kilowatt-hours of electricity, which was about 9.4 percent of the 2,037 billion kilowatt-hours produced by all utilities. By comparison, water power supplied 14 percent of the electricity generated in 1976, coal 46 percent, oil almost 16 percent, and gas somewhat more than 14 percent.[3] The primary energy resources consumed to produce this electricity included 448 million tons of coal, 556 million barrels of oil, 3 trillion cubic feet of natural gas, and 8,132 short tons of uranium oxide (U_3O_8).[4]

As of April 1, 1977, some 232 nuclear powerplants were authorized to operate, or were being built, on order or announced, with a total electrical generating capacity of 231,437 megawatts.[5] Table 18 gives the details.

TABLE 18.—STATUS OF U.S. CENTRAL STATION NUCLEAR CAPACITY

Status [1]	Number of units	Capacity, megawatts electrical (net)
Authorized to operate:		
Licensed by NRC	63	45,454
Authorized by ERDA [2]	2	940
Being built:		
Construction permit	71	74,873
Limited work authorized	18	19,772
Ordered	56	63,738
Subtotal	210	204,777
Announced (but not ordered)	22	26,660
Total	232	231,437

[1] As of Apr. 1, 1977.
[2] Shippingport (90 MWe) and N reactor (850 MWe).

Source: ERDA, U.S. Central Station Nuclear Generating Units. Op. cit.

[2] Until recently, it was argued that the presence of comparatively high concentrations of the plutonium isotope-240 in the plutonium-239 produced in breeder reactors made this material unsuitable for nuclear explosives.
[3] U.S. Federal Energy Administration. Energy information. Quarterly report: first quarter 1977, p. 95.
[4] Ibid., p. 99.
[5] U.S. Energy Research and Development Administration. U.S. central station nuclear electric generating units: significa nt milestones. Apr. 1, 1977. Report No. ERDA 77-30/2, p. 12.

As of April 1, 1977, nuclear capacity accounted for 54 percent of the aggregate of the industry's scheduled expansion. During the last nine months of 1977, eight nuclear power units are scheduled for commercial operation, with a total capacity of 7,700 megawatts.[6]

Although for the nation as a whole, nuclear energy supplied about 10 percent of the electricity in 1976, in three electrical reliability council regions, nuclear provided more than 20 percent, as shown in Table 19.

PART II. FORECASTS FOR NUCLEAR POWER

Quantitative views on the present and future situation for nuclear supply are to be found in forecasts and projections, qualitative views in reports, and analyses.

Some insight into the quantitative aspects of views on nuclear power is to be found in 16 forecasts of government agencies, industrial associations and academic studies, made during the period 1962 to 1977. Table 20 summarizes these forecasts while Figure 1 compares them in terms of publication dates.

The range of forecasts

Beginning with modest projections in 1962, succeeding forecasts rose quickly to peak estimates in 1973 and 1974 and then fell precipitously in the aftermath of the Arab Oil embargo of 1973–1974. The most optimistic forecasts in 1973 and 1974 anticipated as much as 2,000 gigawatts of nuclear electrical generating capacity by the year 2000. Within three years, these had dropped to Secretary Schlesinger's latest figure of 380 gigawatts by the turn of the century.

TABLE 19.—REGIONAL CONTRIBUTION OF NUCLEAR POWER TO GENERATION OF ELECTRICITY, 1976

[Billions of kilowatt-hours]

Region	Nuclear	Total	Nuclear (percent)
NPCC	40.8	187.0	21.8
MAAC	26.2	148.0	17.7
ECAR	13.2	352.8	3.7
SERC	43.8	404.9	10.8
MAIN	35.0	156.1	22.4
SPP	3.8	161.7	2.3
ERCOT		122.0	0
MARCA	22.0	86.7	25.4
WSCC	9.3	383.9	2.4
Total	194.5	2,003.7	9.7

Abbreviations:

NPCC: Northeast Power Coordinating Council; New York and New England.

MAAC: Mid-Atlantic Area Council; New Jersey, Delaware, and parts of Pennsylvania.

ECAR: East Central Area Reliabiltiy Coordination Agreement; West Virginia, Kentucky, Ohio, Illinois, Michigan, and part of Virginia.

SERC: Southeastern Electrical Reliability Council; North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, and parts of Virginia and Mississippi.

MAIN: Mid-America Interpool Network; Indiana and parts of Wisconsin and Missouri.

SPP: Southwest Power Pool; Kansas, Oklahoma, and parts of Texas and Arizona.

ERCOT: Electric Reliability Council of Texas; most of Texas.

MARCA: Mid-Continent Area Reliability Coordination Agreement; Minnesota, Iowa, North Dakota, most of South Dakota, about half of Nebraska, and part of Montana.

WSCC: Western Systems Coordinating Council; Wyoming, Colorado, New Mexico, Utah, Nevada, Idaho, California, Oregon, Washington, and parts of Montana and Arizona.

Source: Edison Electric Institute. 1977 annual electric power survey, 1977, pp. 18–19.

[6] Edison Electric Institute. 1977 annual electric power survey. A report of the Electric Power Survey Committee. 1977, p. 25.

TABLE 20.—COMPARISON OF FORECASTS FOR NUCLEAR ENERGY 1975–2000

[Gigawatts of electrical generating capacity]

Year—Source	1974	1975	1977	1980	1985	1990	1995	2000
1962—AEC [1]		16.0		40.0				
1964—AEC [2]		29.0		75.0				
1966—AEC [3]		40.0		95.0				
1967—AEC [4]		61.0		145.0	255			
1969—AEC [5]		62.0		149.0	277			
1970—AEC [6]		59.0		150.0	300			
1972—AEC: [7]								
Low		52.0		127.0	256	412		825
Most likely		54.0		132.0	280	508		1,200
High		57.0		144.0	332	602		1,500
1974—AEC: [8]								
A—Lowest				85.0	231	410		850
B—Continued improvement				102.0	260	500		1,200
C—Highest				112.0	275	575		1,500
1974—FEA:								
Project Independence Blueprint Report [9]				93.0	240			
Nuclear Task Force Report:								
Business-as-usual scenario [10]				120.0	275	500		
Accelerated scenario [11]				150.0	400	750		
1976—ERDA: [12]								
Low estimate		39.0		60.0	127	195		380
Medium estimate		39.0		67.0	145	250		510
High estimate		39.0		71.0	166	290		620
1976—NRC (Gesmo Report) [13]		37.0		71.0	156	269	400	507
1976—EEI: [14]								
Low estimate				73.0	157	213		507
Moderate estimate		39.5		78.0	185	340		805
High estimate				85.0	204	389		1,005
1977—FEA [15]			51.0	75.0	135	NA		
1977—WAES: [16]								
Installed capacity	404							
Minimum likely					127			380
Maximum likely					166			620
1977—ERDA: Base case [17]		43.0	47.9	61.1	127	195	283	380

[1] U.S. Atomic Energy Commission. Report to the President on Civilian Nuclear Power. 1962. Table 16, app. IV.
[2] U.S. Atomic Energy Commission. Estimated growth of civilian nuclear power. 1965. AEC Report, WASH-1055.
[3] U.S. Atomic Energy Press Release S-20-66 of June 7, 1966, and table 1 of AEC Press Release S-23-66, Sept. 8, 1966.
[4] U.S. Atomic Energy Commission. Forecast of growth of nuclear power. 1967. AEC Report, WASH-1084.
[5] U.S. Atomic Energy Commission. Unpublished forecast. May 1969.
[6] U.S. Atomic Energy Commission. Forecast of growth of nuclear power. January 1971. AEC Repor , WASH-1139.
[7] U.S. Atomic Energy Commission. Nuclear power, 1973–2000. Dec. 1, 1972. AEC Report, WASH-1139 (72).
[8] U.S. Atomic Energy Commission. Nuclear power, 1974-2000. February 1974. AEC Report, WASH-1139 (72).
[9] U.S. Federal Energy Administration. Project Independence Report. November 1974, p. 113.
[10] U.S. Federal Energy Administration. Project Independence Blueprint. Final task force report on nuclear energy. November 1974, p. 3.1-1.
[11] Ibid., p. 3.1-2.
[12] Edward J. Hanrahan, Richard H. Williamson, and Robert W. Brown. U.S. uranium requirements. In U.S. Energy Research and Development Administration. Uranium industry seminar. October 1976. AEC Report, GJO-108 (76) vol., p. 55.
[13] U.S. Nuclear Regulatory Commission. Final generic environmental statement on the use of recycle plutonium in mixed oxide fuel in light water-cooled reactors. August 1976. NRC Report, NUREG-0002, vol. 2, p. III-3. (Gesmo Report.)
[14] Edison Electric Institute. Nuclear fuels supply. Appendixes to the report of the Edison Electric Institute on nuclear fuels supply. 1976, p. 63.
[15] U.S. Federal Energy Administration. Energy information. Quarterly Report: 1st Quarter 1977. 1977, p. 77.
[16] Carroll L. Wilson. Energy: global prospects 1985–2000. Report of the Workshop on Alternative Energy Strategies. New York: McGraw-Hill Book Co., 1977. p. 203.
[17] U.S. Energy Research and Development Administration. Unpublished information. April 1977.

Notes: AEC=U.S. Atomic Energy Commission; FEA=U.S. Federal Energy Administration; ERDA=U.S. Energy Research and Development; NRC=U.S. Nuclear Regulatory Commission; EEI=Edison Electric Institute; WAES=Workshop on Alternative Energy Strategies.

The great variation among these 16 forecasts gives good reason to be wary of current projections as guides to the future or as the principal basis for decisions about the future of nuclear power. Forecasts are useful to test the possible effects of optimism or pessimism for the future of nuclear energy. They may even suggest short-term changes in nuclear power plans of the Government and industry. But they cannot be trusted to give a reliable picture of the future beyond a few years.

Sources of variations

The variations in these 16 forecasts result from many influences. Some come from within the nuclear power industry, others are external to it. The Nuclear Fuels Supply Study Program of the Edison Electric Institute in 1975 commented on uncertainties it had seen in nuclear forecasting. It observed that while relatively low fuel cost experience and projections favor nuclear power, high and escalating initial costs (due in part to long lead times and imposed regulatory criteria), nuclear fuel supply uncertainties and public acceptance problems tend to be encumbering, especially in the United States.[8]

From the viewpoint of national energy policy, many factors in addition to those noted by the Institute contribute to the uncertainty of forecasts for nuclear power and to the ability of the nuclear industry to respond rapidly should national policy opt for more nuclear power in the future. A list of these factors and constraints appears in Table 21. For the future of nuclear power projected by the Administration, the nuclear power in 1985 will provide 20 percent of the electricity generation, the social, political and regulatory factors appear more influential than resource and technological factors. It should be kept in mind that the present U.S. nuclear power industry will need a minimum number of new orders from year to year if it is to retain its present production capacity. If the present industrial base for nuclear power is reduced by attrition as manufacturers drop out or combine with others, then the future option to enlarge the presently projected expansion of nuclear power will be constrained, at least for the time needed to reestablish lost capacity.

TABLE 21.—LIST OF FACTORS LIKELY TO AFFECT THE FUTURE SUPPLY OF NUCLEAR ENERGY IN THE UNITED STATES

Factors	1977–85	1986–2000	2000+
Public policy:			
National actions by the President and Congress	×	×	×
State government actions	×	×	×
Economic trends:			
Future growth in demand for electricity	×	×	×
Comparative costs of alternatives to nuclear power	×	×	×
Resources:			
Supplies of uranium	×	×	×
Supplies of thorium			×
Supplies of coal, oil and natural gas	×	×	×
Industrial capacity:			
Uranium mining and milling	×	×	
Uranium enrichment		×	×
Storage of spent fuel	×	×	?
Reprocessing of spent fuel	?	×	×
Management of high-level wastes	?	?	×
Technological devlopments:			
Development of the plutonium breeder		?	×
Development of acceptable plutonium recycle	?	×	×
Development of other ways to get more energy out of uranium which are also proliferation resistant		?	×
Regulation of burning of coal to generate electricity—by EPA and States	?	×	×
Regulation of nuclear energy:			
Economic—by State utility commissions	×	×	×
Environmental—by NRC, EPA and States	?	×	×
Public health and safety—by NRC and EPA	×	×	×
National security (nonproliferation) by NRC	×	×	×
Siting—by NRC and States	×	×	×
Public opposition	×	?	?

×=expected effect.
?=possible but uncertain effect.

[8] Edison Electric Institute. Appendices to the Report of the Edison Electric Institute on Nuclear Fuels Supply. December 1975, Appendix I, p. 14.

Forecasts for nuclear power also are susceptible to external events. A catastrophic accident with a nuclear power plant at home or abroad could spark intense pressure for a full or partial shutdown of other nuclear powerplants. On the other hand, failure of coal to supply required generation of electricity, or extension to conventional powerplants of regulations comparable in effect to those now required of nuclear powerplants, or a ceiling or cutoff for foreign oil supply, all could create pressures for acceleration and expansion of nuclear power. Another factor not yet at work could be government policy on whether or not a specified production capacity for nuclear powerplants should be maintained, in the U.S. nuclear industry. If it were deemed necessary, for example, that the present four suppliers of nuclear powerplants preserve their present production capacity, then perhaps six large powerplants would have to be ordered annually. If such new orders are not forthcoming, it is reasonable to expect some companies will leave the nuclear industry or combine their operations with others, which would have important implications for future competition and possible monopoly in the surviving industry.

PART III. SELECTED VIEWS ON NUCLEAR POWER

Supply

Four landmark reports of the last three years provide substantial insights on the future supply of nuclear power. The selected reports include two published soon after the Arab oil embargo of 1973–1974, and two published this year. Two were government and two private. For the immediate post-embargo era, the reports are the Project Independence report of the Federal Energy Agency,[9] and the Energy Policy Project report of the Ford Foundation.[10] For 1977, the reports were the report of the Nuclear Energy Policy Study Group of the Ford Foundation[11] and President Carter's report on his national energy plan.[12]

All of the reports expect there will be nuclear power in the future, but not as much as its proponents expect. The chances that it will supply as much as half of the nation's electrical energy supply by the end of the century are dim. All see many barriers to nuclear supply much greater than present conservative projection. All presume the choices among energy sources will be made by the electric utilities. None inquires whether projections for growth in nuclear power would sustain the present production capacity of the U.S. nuclear industry. None anticipates a nuclear industry independent of government for research and development and for vital services. The U.S. nuclear industry for years to come will depend upon the Department of Energy for uranium enrichment services and probably upon government for long-term storage of spent nuclear fuels and nuclear wastes.

The two latest reports would substantially redirect technological trends in nuclear power by discouraging or prohibiting those nuclear fuel cycles which involve separation of nuclear fuel materials directly usable in weapons, namely plutonium, uranium highly enriched in

---

[9] U.S. Federal Energy Administration Project Independence report. Washington, D.C.: U.S. Govt. Print. Off., November 1974, 443 pp.

[10] The Ford Foundation. A time to choose. Report of the Energy Policy Project. Cambridge, Mass.: Ballinger Publishing Co., 1974, 511 pp.

[11] The Ford Foundation. Nuclear power. Issues and choices. Report of the Nuclear Energy Study Group. Cambridge, Mass.: Ballinger Publishing Co., 1977, 418 pp.

[12] U.S. Executive Office of the President. The national energy plan. Washington, D.C.: U.S. Govt. Print. Off., 1977, 105 pp.

21-616—78——6

U-235 and uranium-233. The immediate change planned is to defer reprocessing of spent fuel to recover plutonium and recycle of that material in fuel for conventional nuclear powerplants. For the longer term, both reports would also redirect nuclear research and development to emphasize "proliferation-resistant fuel cycles," to deemphasize the liquid metal, fast breeder reactor (LMFBR) and to cancel the Department of Energy's construction of a demonstration LMFBR at Clinch River, Tennessee. The second Ford Foundation report also would impose new conditions on exports of the U.S. nuclear industry to make sure these do not contribute to the further spread, or proliferation of nuclear weapons, but gives no idea of the effect of such restrictions on the production capacity of the U.S. nuclear industry.

On the whole, the reports present a curious mixture of pessimism about expected future use, with an implied assumption that nuclear power can be expanded quickly if needed, an assumption that is not tested.

Views of the Federal Energy Administration

Project Independence was a major response of President Nixon's administration to the Arab oil embargo of 1973–1974. The Federal Energy Administration had the task of evaluating the Nation's energy problem and the broad strategic options available to the United States. More recently FEA has been publishing an annual energy outlook. All of these reports include FEA's views on nuclear power, with the later ones reducing the estimates for nuclear power.

The Project Independence Blueprint report.—The FEA, in its Project Independence Blueprint report of November 1974, forecast base-case nuclear power would grow from 4.5 percent to 30 percent of total electric power generation, an increase from 36,000 megawatts in 1974 to 204,000 megawatts by 1985.[13] FEA's estimate was notably lower than other forecasts at this time because of its assessment of construction schedule deferments and delays and operating problems. FEA's projections for nuclear power and other energy sources for the base case and for an accelerated case appear in Table 22. Note

TABLE 22.—FEA ESTIMATES OF DOMESTIC FUEL CONSUMPTION, 1985

[Quadrillion Btu]

		$7 oil			$11 oil		
Fuel source	1972 actual	Base case	Accelerated supply case	Percent change	Base case	Accelerated supply case	Percent change
Coal	12.5	19.9	17.7	−11.0	22.9	20.7	−9.6
Oil	22.4	23.1	30.5	+32.0	31.3	38.0	+21.4
Gas	22.1	23.9	24.7	+3.3	24.8	25.5	+2.8
Hydro and geothermal	2.9	4.8	4.8	0	4.8	4.8	0
Nuclear	.6	12.5	14.7	+17.6	12.5	14.7	+17.6
Synthetics			0			.4	
Imports	11.7	24.8	17.1	−31.0	6.5	0	−100.0
Total	72.1	109.1	109.6	+.4	102.9	104.2	+1.2

Source: U.S. Federal Energy Administration. Project Independence. A Summary. Washington, D.C.: U.S. Government Printing Office, 1974, p. 46.

[13] U.S. Federal Energy Administration. Project Independence report. Op. cit., p. 6.

FEA's anticipation that nuclear power generation could be expanded by 18 percent from the base case to the accelerated case figure. This expansion, said FEA, would have no impact on imported oil, but rather would reduce the growth of new coal-fired capacity.[14]

The FEA expected that increasing oil prices would not cause an increase in nuclear energy in 1985, and that projected exploration, mining and milling for uranium would fail to meet nuclear fuel requirements for its accelerated case unless uranium production could be more than doubled between 1980 and 1985. FEA was pessimistic about the ability of the nuclear industry to achieve even its low estimate. Of this it said: [15]

> To achieve even the low estimates of nuclear growth would necessitate a reversal of recent trends in the ability of utilities to raise investment funds and in equipment delivery and construction schedules, as well as a reduction in licensing delays. Achievement of high levels of nuclear power could require a national commitment of manpower and other resources. The long lead time required to achieve nuclear capacity additions severely limits the possibility of increasing the number of nuclear plants which could become operational before the early 1980's.

The FEA's estimates assumed reprocessing of nuclear fuel and recycling of recovered plutonium, noting that this could reduce new uranium requirements by about 15 percent and enrichment services by about 20 percent. However, the reprocessing capacity expected to be in service by 1977–78 would be adequate only through 1980 and would meet only half of the 1985 requirements.[16]

For the FEA, public acceptance of nuclear power was an important constraint. "Utility planning, site availability, licensing schedules, and implementation of measures to shorten the construction period are all influenced by public acceptance." [17]

Looking to the post-1985 era, the FEA expected light-water reactors to increase their contribution to electric power generation from about 30 percent in 1985 to as much as 70 percent by the year 2000. However, some problems remained to be solved:

> * * * Some remaining issues in the fuel cycle (e.g., plutonium recycle, enrichment and high-level waste disposal) require continued research. These issues ought to be resolved as soon as possible so that the projected growth of nuclear power can be realized. In addition, R & D aimed at improving performance and reliability, and speeding construction could have large short-term benefits.[18]

The FEA's Nuclear Task Force report.—FEA's Nuclear Task Force for Project Independence was more optimistic about nuclear power than the Agency itself.[19] The Task Force expected substantial growth for nuclear energy through 1990, projecting 500 gigawatts of electrical generating capacity for a business-as-usual scenario and 730 GWe for accelerated development. Table 23 gives the details.[20]

---

[14] Ibid., p. 49.
[15] Ibid., p. 115.
[16] Ibid., p. 114.
[17] Ibid., p. 115.
[18] Ibid., p. 427.
[19] U.S. Federal Energy Administration. Project Independence Blueprint. Final Task Force Report. Nuclear Energy. Washington, D.C.: U.S. Govt. Print. Off., November 1974, various pagings.
[20] Ibid., p. IV-4.

TABLE 23.—FEA PROJECT INDEPENDENCE BLUEPRINT NUCLEAR TASK FORCE PROJECTED NUCLEAR GENERATING CAPACITY

	Nuclear task force projections (gigawatts electrical)	
	Business as usual	Accelerated case
1977	61	72
1980	120	150
1985	275	400
1990	500	730

The Task Force concluded that use of nuclear power in the electricity industry is characterized by specific resource limitations and is influenced by regulation and control. Excerpts from its eleven principal findings follow: [21]

1. There are significant economic, fuel resource and environmental benefits to be derived from the increased use of nuclear power systems.
2. The ability to increase rapidly the generation of electrical energy by nuclear systems is severely limited.
3. The current difficulties in the Nation's electric utilities in financing generating, transmission and distribution system expansions is having a serious impact on the plans to provide nuclear capacity additions.
4. In the light of the current and projected frame of reference, the accelerated program laid out by the Task Force cannot be met in the near term and could be approached in the long term only through a major national commitment approaching a crash program.
5. There is a moderate-to-high risk that the lower projections considered reasonable by the Task Force will not be met unless immediate attention is given to existing problems and recent trends are reversed.
6. Public acceptance of nuclear power is an important factor in the ability to bring about a timely correction of many of the current problems constraining the increased use of nuclear power.
7. Action is needed now, or within the next several months, to assure that the availability of domestic nuclear fuel supplies and fuel cycle facilities will not limit the increased use of nuclear power in the 1980s.
8. Action is needed to remove uncertainties currently complicating long-range utility planning.
9. Greater attention needs to be given to the operational reliability of nuclear plants and the contained systems and components. At the same time, more effective measures, requiring less time and labor, are needed to assure high quality in the design, manufacture and installation of components, and the construction of nuclear powerplants.
10. Improved labor productivity is essential if escalation of powerplant construction costs is to be brought under control.
11. Resource problems other than fuel supply and financing could constrain the rate of increase in the use of nuclear power. Potentially serious problems exist with respect to materials and equipment, manpower and the availability of powerplant sites.

FEA's national energy outlook for 1976.—In its national energy outlook for 1976, FEA cut back its forecast for nuclear energy.[22] As

[21] Ibid., pp. 2. 0–1, 2. 0–9.
[22] U.S. Federal Energy Administration. National energy outlook, 1976. Washington, D.C. U.S. Govt. Print. Off., 1976, 323 p.

of February 1976, FEA expected nuclear generating capacity to increase to 152 GWe by 1985, in comparison with the 204 GWe of the Blueprint report.[23] The reason was deferral or cancellation of about 105 GWe of new nuclear capacity during the 18 months preceding the new report, which affected almost 70 percent of planned nuclear additions and occurred, according to FEA, because of lower projections of electricity demand, financial problems experienced by utilities, uncertainty about government policy, and continued siting and nuclear licensing problems. Even with this reduced forecast, nuclear power would still provide almost 26 percent of electric power generation in 1985, in comparison with 8.6 percent in 1975. Elaborating on this revision and its implications, FEA said:[24]

> Although nuclear power estimates in the Reference Scenario are considerably lower than last year's forecast, policy and regulatory decisions could dramatically change these estimates. For example, if the lead time from the inception to operation of a nuclear powerplant could be reduced from 10–12 years to 5–7 years, the effects of inflation would be reduced, capital costs would decline, and more nuclear plants would be built. FEA estimates that under such an accelerated nuclear strategy, about 142,000 MWe of new nuclear capacity could be added by the end of 1984 * * *.

Views of the Ford Foundation's Energy Policy Project

In 1974, shortly after the Arab oil embargo, the Energy Policy Project of the Ford Foundation published its final report: A Time to Choose. The report is notable both because of the heated discussion it generated over concepts such as zero energy growth and the decoupling of energy from the economy, and because the project director was S. David Freeman who until recently was a principal participant in the drafting of President Carter's energy plan and now is a commissioner of the Tennessee Valley Authority.

The Energy Policy Project, after contrasting advantages and disadvantages of nuclear power, took a dim view of this energy source. Table 24 summarizes the role it assigned to nuclear power for generation of electricity in the three scenarios developed by the project. After postulating a scenario for high energy growth that had nuclear power supplying more than half the electricity by the year 2000, the project rejected this approach and instead opted for its zero-growth scenario in which by the year 2000 nuclear energy would supply about

TABLE 24.—FUELS FOR CENTRAL STATION ELECTRIC POWER

[Quadrillion Btu]

	1973		1985		2000	
	Nuclear	Total	Nuclear	Total	Nuclear	Total
High-growth scenario:[1]						
Case 1	0.9	19.8	10	37	40	74
Case 2	.9	19.8	12	37	50	80
Case 3	.9	19.8	10	37	40	74
Technical fix scenario:						
Case 1	.9	19.8	8	24	11	31
Case 2	.9	19.8	5	24	3	31
Zero-growth scenario:[3]	.9	19.8	5	23	3	31

[1] Ford Foundation. A time to choose. Op. cit., p. 28.
[2] Ibid., p. 76.
[3] Ibid., p. 111.

[23] Ibid., p. 36.
[24] Ibid., p. 38.

10 percent of the electricity, scarcely three times the amount it supplied in 1973. Table 25 lists the advantages and disadvantages mentioned by the report.

In analyzing the high-growth scenario, in which energy use increased each year at a rate of 3.4 percent, the project noted that the main obstacles to expansion of nuclear power were the limited uranium enrichment capacity, the shortage of skilled labor to meet construction schedules, and the poor reliability of operating plants. These problems would have to be solved quickly. The project noted that in the long run, the breeder reactor, if it passes the tests of safety and economics, would greatly extend the energy potential of the uranium resource base.[25]

TABLE 25.—*List of advantages and disadvantages of nuclear power from the energy policy project report of the Ford Foundation*

ADVANTAGES

The potential for meeting a significant fraction of U.S. energy needs far into the future. If the breeder reactor is successfully developed, low-cost U.S. uranium resources could meet electric energy needs for thousands of years.

A potential alternative to U.S. heavy reliance on oil and gas.

Over the longer term, nuclear power might displace liquid fossil fuels in transportation, through electrified transportation or through manufacture of hydrogen fuel.

Foreign policy benefits since nuclear power can make up much of the growth in electric power that otherwise might require increased oil imports.

Significant advantages in terms of air pollution and land use. "The clean air benefit of nuclear power is especially important while we learn to burn coal in an environmentally acceptable manner."

DISADVANTAGES

The risk of a catastrophic releases of radioactive materials.

The risk of release of radioactive materials from spent fuel in transport accidents.

The possibility that quality control standards for nuclear power may not be achievable.

The difficulty of permanent management of radioactive wastes from nuclear power.

The unknown costs and problems of decommissioning and disposal of obsolete nuclear facilities.

The risks of acts of nuclear violence.

The proliferation of nuclear weapons.

The risk of theft of nuclear materials by terrorist groups.

Source: The Ford Foundation. A time to choose. Op. cit., pp. 203–215.

The Project concluded that current projections of the then AEC for expansion of the 1973 nuclear generating capacity of 25 gigawatts by more than tenfold by 1985 and twentyfold by 1990 would make it nearly impossible to resolve all of its concerns with nuclear power in time to avoid catastrophe if these fears were well founded. If energy conservation were pursued as a serious national objective, the country could get a breathing period to reassess its entire nuclear program, without foreclosing any of the options regarding nuclear power development.[26]

On the whole, the Project expected that total U.S. energy requirements, even at lower growth rates, would require continued expansion

---

[25] The Ford Foundation. A time to choose. Op. cit., p. 332.
[26] Ibid., p. 223.

of conventional supplies. Consequently, there must be either major commitments to at least two of the four troublesome energy sources—oil imports, nuclear power, coal and shale, or drilling in the Gulf of Alaska and off the East and West coasts—or the United States must go ahead with all four on a more moderate scale.[27]

Summing up its views, the Report said.[28]

> Nuclear fission is potentially a very large source of energy. Nuclear energy is free of air pollution, generally requires less land in providing energy and, in the long run, allows us to avoid some of the global climatic problems that may be associated with the burning of fossil fuels. But the problems of reactor safety, nuclear theft, the proliferation of nuclear weapons through diversion of fissionable materials, and ultimate disposal of nuclear wastes are as yet unresolved. Moreover, the problems of our institutional capabilities for dealing with these issues have not yet been squarely faced. Resolution of these problems should come before, not after, a high-level of nuclear capacity is installed.
>
> Nuclear power is currently growing at a tremendous rate. But the current projections are based on the historical rate of growth in energy, which is high. Our studies show that a much slower rate for nuclear power is adequate to meet energy needs, if the conservation-oriented policy we recommend is implemented. We do not advocate an absolute ban on new nuclear plants because the problems posed by using fossil fuels instead are also serious. But a conservation-oriented growth policy will provide breathing room so that we can gain a better understanding of nuclear power problems, and reach some better judgments before major new expansions of nuclear power are made.

As for the breeder, the Project found the Government's development program to be "* * * an outstanding example of the neglect of public participation as well as independent assessment, and of failure to protect the public treasury." It recommended an end to open-ended government funding of the liquid metal fast breeder demonstration. Also, it called for an independent assessment of the state of reactor technology and its associated health, safety and environmental problems, to be undertaken by the National Academy of Science on an urgent basis so that the public may have the opportunity of debating the desirability of proceeding with the demonstration plant. When that desirability is established, the demonstration project should be funded with much more participation from the nuclear industry.[29]

Views of the Ford Foundation's Nuclear Energy Policy Study Group

Early in 1977 the report of the Ford Foundation's Nuclear Energy Policy Study Group was hurried into print. It is widely believed to have provided much of the foundation for the President's policy statements in April dealing with preventing the spread or proliferation of nuclear weapons. These policies have changed the future of nuclear power in the United States. One member of the Study Group, Dr. Joseph S. Nye, Jr., is now a leading official in the State Department concerned with nonproliferation. The chairman of the Study Group, Spurgeon M. Keeny, Jr., has since been appointed deputy director of the U.S. Arms Control and Disarmament Agency.

Because of the current impact of this report, its conclusions and recommendations will be described in detail.

The Study Group's primary task was to develop a framework for decision-making about nuclear power. To do so, it described and analyzed alternatives and offered its best judgment on a number of

---

[27] Ibid., p. 331.
[28] Ibid., p. 338.
[29] Ibid., p. 313.

decisions including: (1) the reprocessing and recycle of plutonium, (2) the breeder reactor program, (3) the management of nuclear wastes, (4) the expansion of uranium enrichment capacity, and (5) the export of nuclear technology and materials. The first four bear directly upon the future of U.S. nuclear energy supply, and the last, indirectly through its implications, bears upon the future health of the U.S. nuclear power industry.

The current status of nuclear power.—Nuclear power is a present reality, not a future prospect. Although there has been a substantial cutback in plans for both U.S. and foreign nuclear power since 1974, this reduction appears to result primarily from economic recession rather than from a rejection of nuclear power.[31]

No need for plutonium.—The common thread in these decisions is the question of whether plutonium should be introduced into the nuclear fuel cycle. The Study Group concluded that there is no compelling reason at this time to introduce it or to anticipate its introduction in this century. Elaborating on this point, the Study Group said: [32]

> * * * Plutonium could do little to improve nuclear fuel economics or assurance here or abroad. This conclusion rests on our analysis of uranium supply, the economics of plutonium recycle in current reactors, and the prospects of breeder reactors. In the longer term, beginning in the next century, there is at least the possibility that the world can bypass substantial reliance on plutonium. If this is not the case, the time bought by delay may permit political and technical developments that will reduce the nuclear proliferation risks involved in the introduction of plutonium.

Plutonium reprocessing and recycle.—The principal immediate issue for the Study Group was whether the United States should proceed with the reprocessing and recycle of plutonium. It concluded that the international and social costs involved far outweighed economic benefits, which would be very small even under optimistic assumptions.

> We believe, therefore, that a clear-cut decision should be made by the U.S. Government to defer indefinitely commercial reprocessing of plutonium.[33]

Proliferation-resistant nuclear power.—By far the most serious danger associated with nuclear power is that it provides additional countries a path for access to equipment, materials, and technology necessary for the manufacture of nuclear weapons. "We believe the consequences of the proliferation of nuclear weapons are so serious compared to the limited economic benefits of nuclear energy that we would be prepared to recommend stopping nuclear power in the United States if we thought this would prevent further proliferation."[34] However, the Study Group did not go that far because there are direct routes to nuclear weapons in the absence of nuclear power, and the future of world nuclear power is not under the unilateral control of the United States. So abandonment of nuclear power in the United States could increase the likelihood of proliferation through United States' loss of influence over nuclear power development abroad.

With this in mind, the Study Group argued for postponing plutonium recycle and the plutonium breeder, and for assured supplies of slightly enriched uranium at reasonable prices to reduce the economic rationale abroad for indigenous enrichment plants. "Within such a

[31] Ibid., p. 5.
[32] Ford Foundation. Nuclear power, issues and choices. Op. cit., p. 29.
[33] Ibid., p. 31.
[34] Loc. cit.

framework of national and international constraints on the nuclear fuel cycle, we believe that, with concerted efforts by the United States and the international community to meet national security concerns and to reduce international tensions, the risk that nuclear power will lead to proliferation can be substantially reduced."

Uncertain economic advantage.—The Study Group's analysis indicated that nuclear power has and will probably continue to have a small economic advantage over coal. Moreover, the ranges of possible social costs, including health and environmental impacts associated with coal and nuclear power, also overlap to such an extent that neither has a clear advantage. "We find such large uncertainties and unknowns in both the economic and social costs that the average comparative advantage could shift either way in the future." [35]

The Study Group concluded that nuclear power on the average probably will be somewhat less costly than coal-generated power. However, coal will continue to be competitive or preferable in many regions. The advantage for nuclear power is likely to be most significant in New England and in parts of the South.[36]

Ample uranium supplies.—The Study Group was convinced that official estimates of uranium reserves and resources substantially underestimated the amounts of uranium that will be available at competitive costs. "We believe that there will be enough uranium at costs of $40 (1976 dollars) per pound to fuel light-water reactors through this century and, at costs of $40 to $70 per pound, well into the next century." [37]

Alternative sources of energy.—It is frequently argued, the Study Group noted, that solar, geothermal, or fusion energy would be viable alternatives to nuclear power if they received a fair share of research and development funds. The Study Group disagreed. "It is our judgment that these forms of energy cannot compete with nuclear, coal, or other fossil fuels as major sources of electric power until well into the next century." [38] Vigorous research and development, however, should be carried out for these alternatives to develop the long-range options and to provide a hedge against possible unforeseen problems with fossil or nuclear power.

The limited effect of nuclear power on energy costs.—Whatever is done about nuclear power over the coming decades, real energy costs will continue to increase into the next century. Whatever the income loss due to higher energy costs, nuclear power can do little to reduce it since nuclear power at best will have only a small cost advantage over coal. Even with assumptions favorable to nuclear power, the benefits from the continued growth of light-water reactors and the early introduction of the breeder are very small in this century, much less than one percent of gross national product, and only one or two percent in the next century. Nuclear power will have little to do with the cause, severity, or duration of sudden stoppages or sharp price increases for other energy supplies. The choice between coal and nuclear power will have little or no effect in insulating the

---

[35] Ibid., p. 4.
[36] Ibid., pp. 7, 8.
[37] Ibid., p. 9.
[38] Ibid., p. 12.

United States from the short-term effects of sudden changes in oil prices and availability.[39]

Health, environment and safety.—Nuclear power is seen as a threat to human health by critics primarily concerned about the possibility of catastrophic reactor accidents and risks associated with nuclear wastes and plutonium. "These risks are real and must be considered in any assessment of nuclear power." [40] The uncertainties in estimates of social costs for coal and nuclear power are so great that the balance between them could be tipped in either direction. It is unlikely, however, that the principal uncertainties soon will be resolved. "We do not believe, therefore, that consideration of social costs provides a basis for overriding our conclusions, based on economic analysis, of the comparative attractiveness of the two technologies and the desirability of maintaining a mix." [41]

Having examined nuclear accidents with very pessimistic assumptions, the Study Group concluded that even when their possibility is included, the adverse health effects of nuclear power are less than or within the range of health effects from coal." [42] This analysis underscored the importance of continuing efforts to reduce the probability and consequences of accidents by improved safety designs and siting policies for nuclear powerplants.

The breeder reactor.—The Group's analysis indicates that the early economic potential of the breeder was significantly overstated. As planned, LMFBR would have higher capital costs than conventional power reactors and therefore would have to operate at significantly lower fuel cycle costs to be economically competitive. The Study Group found little prospect that these fuel cycle costs could be reduced enough to give the LMFBR a significant economic advantage over the light water reactors in this century or in the early decades of the next. Also, the current assessment of uranium reserves probably substantially understated the supplies that would be available. Uranium at prices making LWRs competitive with breeders will be available for a considerably longer time than previously estimated. New enrichment technologies may also extend these supplies. Moreover, coal available at roughly current costs will look increasingly attractive if the costs of nuclear power rise. Finally, demand projections on which breeder economic assessment have been made in the past were unrealistically high. For these reasons, the Study Group concluded that the economic incentive to introduce breeders will develop much more slowly than previously assumed in government planning.[43]

Despite this negative assessment, the Study Group believed that a breeder program with restructured goals should be pursued as insurance against very high energy costs in the future.[44]

This situation could develop if additional uranium reserves do not become available, environmental problems place limits on the utilization of coal, and other alternative energy soiuces do not become commercially viable at reasonable prices in the first decades of the next century.

---

[39] Ibid., pp. 14–15.
[40] Ibid., p. 16.
[41] Ibid., p. 17.
[42] Ibid., p. 1.
[43] Ibid., p. 32.
[44] Ibid., p. 33.

However, the present U.S. program for early commercialization of the LMFBR is not necessary. The Group believed that the breeder should deemphasize such early commercialization and emphasize a more flexible approach to the basic technology. The Clinch River project was unnecessary and could be canceled without harming the long-term prospects of breeders. The time for decision on commercialization of the breeder can safely be postponed beyond the end of the century. "The cost, if any, of such postponement will be small, and there is a strong possibility that postponement will help in restraining large-scale, worldwide commerce in plutonium and buy time to develop institutions to deal with this problem."[45]

Nuclear waste management.—The Study Group called for improved management of nuclear wastes and a prompt decision on the strategy for its disposal. It was convinced that nuclear wastes can be disposed of permanently with acceptable safety by deep burial in salt and other stable geological formations isolated from ground water. As for spent fuel, for the immediate future it can be kept in cooling ponds at nuclear powerplants, which can be easily expanded. For the longer term, there should be both permanent and retrievable and irretrievable storage for spent fuel. While security of storage will have to be balanced against ease of retrieval, the emphasis should be on security since retrieval may be long-delayed or perhaps unnecessary. The United States also should be willing to take back spent fuel from countries lacking storage or disposal facilities if this would reduce risks to international health or of proliferation.

Expansion of uranium enrichment capacity.—According to the Study Group, the United States must have a clear policy on its long-term role in providing enriched uranium to both domestic and foreign nuclear power programs. Present facilities will eventually have to be expanded. The timing and magnitude of this expansion depends not only on the anticipated growth of domestic demand for enriched uranium but also on the extent to which the United States wishes to be able to assure fuel for others.[46] An assured supply of uranium fuel would be a major factor in limiting worldwide proliferation capabilities.

> The assured availability of fuel at reasonable prices limits the pressure on other countries to seek indigenous enrichment facilities that would provide a capability leading to weapons. An assured fuel supply also reduces the incentive to recycle plutonium or develop breeders.[47]

The Study Group believed the United States should maintain adequate uranium enrichment capacity to meet worldwide nuclear power requirements. However, in view of rapidly changing demand projections and the possibility of radical technological developments, decisions should not be made hastily.[48]

The President's plan

On April 29, 1977, President Carter published the report on his National Energy Plan. The Plan contemplated a growing but still last-resort use of nuclear power. It would indefinitely defer development and use of those nuclear power technologies that produce or require plutonium or highly enriched uranium for nuclear fuel because

---

[45] Loc. cit.
[46] Ibid., p. 35.
[47] Loc. cit.
[48] Ibid., p. 36.

these materials can be used directly to make atom bombs. Reprocessing of spent fuel and recycling of recovered plutonium would not be permitted. Permissible nuclear power technology would be confined to the present light-water-type reactors which are fueled with slightly enriched uranium, and, if they can be successfully developed, other types of reactors that do not use or produce weapons-grade materials. The Plan contains four measures to prevent or defer commercial production and use of plutonium, including cancellation of the Clinch River breeder demonstration; one to restore the United States' reputation as a reliable supplier of uranium enrichment services; one to provide better information about U.S. uranium resources; three additional to assure safety of nuclear powerplants; and finally one each to expedite licensing of nuclear powerplants, provide techniques for storage of spent nuclear fuel and review ERDA's radioactive waste management program. These measures are summarized below.

The Plan estimated that nuclear power under the Plan would provide energy equivalent to 3.8 million barrels of oil per day by 1985, in comparison with the equivalent of 3.6 million without the Plan.[49] This corresponds to a nuclear generating capacity of 141 gigawatts operating with a capacity factor of 65 percent.

The Plan notes that the currently projected growth rate of nuclear energy is substantially below prior expectations, due mainly to the recent drop in demand for electricity, labor problems, equipment delays, health and safety problems, lack of a publicly accepted waste disposal program and concern over nuclear proliferation.[50] Federal policy should stimulate the expanded use of coal, supplemented by nuclear power, to fill the gap between energy demand and a relatively stable production of oil and gas.[51] So the Plan counts on nuclear power to meet a share of the energy deficit [52] and says that because there is no practicable alternative, the United States will need to use more light water reactors to meet its energy needs.[53]

GAO analysis of the President's Energy Plan.—The General Accounting Office in its evaluation of the National Energy Plan [54] disagreed with the Administration's proposals to reduce funding of the LMFBR program and to cancel the Clinch River breeder reactor, but agreed with the deferral of nuclear fuel reprocessing. Of these it said:

> As stated above, GAO disagrees with the Administration's proposal to drastically reduce funding for the LMFBR program and, in particular, its decision to cancel the Clinch River Breeder Reactor. GAO sees these actions as reducing the Nation's ability to influence breeder safety and safeguards concerns worldwide.
>
> GAO recommends that the Congress continue the LMFBR program on a schedule which recognizes that it is still a research and development effort, and that the Clinch River project be continued.
>
> GAO agrees with the decision to defer, at least temporarily, nuclear fuel reprocessing. GAO's recent work indicates that the economic benefits of reprocessing do not now outweigh the proliferation and domestic safeguards concerns.[55]

---

[49] U.S. Executive Office oft he President. The National Energy Plan. Op. cit., p. 95.
[50] Ibid., p. 31.
[51] Ibid., p. 63.
[52] Ibid., p. 70.
[53] Ibid., p. 71.
[54] U.S. Comptroller General. An evaluation of the National Energy Plan. Report to the Congress. July 25, 1977, report EMD-77-48, various pagings.
[55] Ibid., p. x.

Excerpts from national energy plan for nuclear power

I. CONTROL OF PROLIFERATION OF THE ABILITY TO MAKE NUCLEAR WEAPONS

Non-proliferating technologies.—The United States should develop advanced nuclear technologies that minimize the risk of nuclear proliferation, but with the knowledge that no advanced nuclear technology is entirely free from proliferation risks.

Plutonium as a nuclear fuel.—It is the President's policy to defer any U.S. commitment to advanced nuclear technologies that are based on the use of plutonium while the United States seeks a better approach to the next generation of nuclear power than is provided by plutonium recycle and the plutonium breeder.

Commercial plutonium reprocessing and the breeder.—The United States will defer indefinitely commercial reprocessing and recycling of plutonium, as well as the commercial introduction of the plutonium breeder.

The President is proposing to reduce the funding for the existing breeder program and to redirect it toward evaluation of alternative breeders, advanced converter reactors, and other fuel cycles, with emphasis on non-proliferation and safety concerns.

The Clinch River Breeder Reactor Demonstration.—The President is proposing to cancel construction of the CRBR Demonstration Project and all component construction, licensing, and commercialization efforts. The design work would be completed, and a base-level program would be maintained, including the Fast Flux Test Facility.

U.S. supply of enrichment services.—The United States must restore confidence in its willingness and ability to supply enrichment services. The Administration, therefore, is prepared, in cooperation with the Congress, to take three steps that will substantially improve confidence in the U.S. position:

(1) to reopen the order books for U.S. uranium enrichment services;

(2) to adopt legislation to guarantee the delivery of enrichment services to any country that shares U.S. non-proliferation objectives and accepts conditions consistent with these objectives; and

(3) to expand U.S. enrichment capacity.

The next U.S. enrichment plant, for which funds are already in the proposed fiscal 1978 budget, will be a centrifuge plant.

Uranium supply.—ERDA will reorient its National Uranium Resources Evaluation Program to improve uranium resources assessment, and to include thorium. The program will be a cooperative effort with industry.

II. ASSURING THE SAFETY OF NUCLEAR POWER

NRC inspection.—The President is requesting the NRC to expand its audit and inspection staff to increase the number of unannounced inspections and to assign one permanent Federal inspector to each nuclear power plant.

Reporting of minor mishaps.—The President is requesting that the NRC make mandatory current voluntary reporting of minor mishaps and component failures at operating reactors, in order to develop the reliable data base needed to improve reactor design and operating practice.

NRC siting criteria.—The President has directed that a study be made of the entire nuclear licensing process. He has proposed that reasonable and objective criteria be established for licensing and that plants that are based on a standard design not require extensive individual licensing.

Spent fuel storage.—ERDA's waste management program has been expanded to include development of techniques for long-term storage of spent fuel.

Radioactive waste management.—A task force under the direction of the Assistant to the President for Energy will review the entire ERDA waste management program.

Source: The National Energy Plan, pp. 69–73.

The Comptroller General agreed generally with five specific proposals of the Plan aimed at improving nuclear power, but noted numerous problems in the way of attempts to streamline licensing of nuclear powerplants.[56]

OTA analysis of the National Energy Plan.—The Office of Technology Assessment published its analysis of the National Energy Plan in June 1977.[57] The OTA thought nuclear power could fall short of the Plan's goal for 1985 by about 18 gigawatts.[58] The policy advisory panel to the OTA generally endorsed the Plan's challenge to the wisdom of relying solely on plutonium breeders for the next generation of nuclear reactors and its redirection of research and development to seek more satisfactory solutions to the problems of nuclear-weapon proliferation.[59]

The OTA identified and analyzed three issues concerning nuclear supply and one concerning the environmental and societal impacts of nuclear proposals.

The OTA concluded it is quite feasible for the nuclear industry to install about 141 gigawatts of nuclear capacity by 1985, which, at a capacity factor of 65 percent, would provide the energy equivalent of 3.8 million barrels of oil per day with the plan, or 3.6 million barrels per day without the plan.[60] Production capacity of the industry is adequate for all components, according to OTA, and uranium ore and enrichment demands are well within present capacity projections. A continuation of financial pressures on utilities and regulatory changes could introduce some slippage into the schedule and reduce available generation capacity. OTA noted that the source of the small increase in nuclear generation projected by the plan was not explained.

OTA also noted that the de facto moratorium on new orders for nuclear powerplants showed no sign of ending and mentioned public acceptance as a critical factor. Of the latter, it said: [61]

> * * * Opposition has been increasing over the years and a significant fraction of the general public adamantly rejects the technology. Some arguments, particularly those centered on technological issues, can be effectively answered or shown to be subject to eventual resolution. Others, however, raise philosophical questions concerning the ability of our present institutions, or even of society in general, to cope with nuclear power. This opposition, especially as manifested in lawsuits and intervention in the licensing process, has become an important consideration for utilities planning on nuclear powerplants.

---

[56] The five proposals GAO agreed to were: (1) increased surprise inspections and resident inspectors at each nuclear site, (2) mandatory reporting of minor mishaps and component failure at powerplant sites, (3) improved powerplant siting criteria, (4) improved powerplant licensing procedures, and (5) detailed review of the nuclear waste disposal program.

[57] U.S. Office of Technology Assessment. Analysis of the proposed National Energy Plan. June 1977, 281 p. (Prepublication draft).

[58] Ibid., p. 5.

[59] Ibid., p. 143.

[60] Ibid., p. 65.

[61] Ibid., p. 66.

As for the Plan's proposals for breeder development, OTA noted considerable concern has been expressed over the lack of a readily available substitute. "Without some sort of breeder, nuclear capacity will be limited to several hundred reactors, depending on the extent and extractability of as yet undiscovered ores." [62] Other breeder concepts less vulnerable to proliferation are less advanced than the LMFBR.

Summarizing, the OTA said the Plan provides only vague suggestions for increasing nuclear energy use and at the same time it virtually eliminates the long-term expectations of the industry. "If Congress decides that nuclear power is to be an integral part of the Nation's energy future, more positive steps than those proposed in the Plan may be required to help the industry overcome problems." [63]

Table 26 lists four issues identified by OTA that relate to nuclear power and the specific questions these pose.

CRS analysis of the President's Plan.—In June 1977, the Congressional Research Service delivered to the House Committee on Interior and Insular Affairs a draft analysis of the President's National Energy Plan.[64] The CRS analysis observed that the Plan reflected the President's view that nuclear energy should be the energy source of last resort. While the Plan expected nuclear power generation to increase almost fourfold by 1985, this expansion could be filled simply by construction in progress and nuclear plants on order or announced. The Plan implied a lean market for new orders for the nuclear industry and the prospect that by 1985 the industry would be weaker and less able to respond to a future decision to expand nuclear power.

Preventing the domestic production and use of plutonium could put the U.S. nuclear industry at a competitive disadvantage in the world market if other nations do not follow the U.S. example. Of course, if foreign ventures should prove uneconomic, then the U.S. nuclear industry would be better off.

---

[62] Ibid., p. 66.
[63] Loc. cit.
[64] At the time of writing, arrangements were being made by the House Committees on Interior and Insular Affairs and on Interstate and Foreign Commerce to have the CRS report printed.

TABLE 26.—*List of issues and questions about nuclear energy. Presented in the Office of Technology Assessment's analysis of the proposed national energy plan*

ISSUE NO. 1: LICENSING REACTORS [1]

If nuclear power is to provide a significant fraction of new energy sources after 1985, constraints that have led to a virtual moratorium on contracts for new plants will have to be removed in an acceptable manner.

Questions

(1) How will the study of the licensing process be conducted?
(2) How is the licensing process to be streamlined while maintaining the highest degree of safety and the legal rights of the intervenors?
(3) How will plant capacity factors be increased?

ISSUE NO. 2: PUBLIC ACCEPTANCE [2]

Are growing public attitudes of skepticism and hostility toward nuclear power irreversible?

Questions

(1) What are the plans for addressing the causes of opposition?
(2) How is the general public to be supplied with credible information on nuclear energy?
(3) Will light water reactor safety research be augmented?

ISSUE NO. 3: BREEDER REACTORS [3]

Nuclear generation of electricity can be virtually freed from resource constraints, but the technologies that will allow this (breeders and plutonium recycle) increase the opportunities for proliferation of nuclear weapons among nations and terrorists.

Questions

(1) What will be U.S. policy toward plutonium recycle and the liquid fast breeder if other nations continue to refuse to defer development of the technologies?
(2) What would be the mid-term and long-term strategies for nuclear energy if reserves prove to be lower than expected?
(3) If alternative fuel cycles prove more attractive with nonproliferation as a major parameter, how will they be implemented both in this country and abroad?

Issue No. 4: Impacts of nuclear power [4]

The National Energy Plan's proposal to increase nuclear electricity generation raises environmental and social questions.

Questions

(1) If a standardized nuclear plant design were to be developed in the next several years, how would this affect the development of safer light water reactor designs in later years?
(2) What new or increased light water reactor safety research programs are proposed?
(3) Should a cutoff date be established for settling on an acceptable method for disposing of nuclear fission wastes?
(4) In what ways might the protection of nuclear reactors from sabotage abridge the civil liberties of the American people?
(5) What is the potential for nuclear power generation to be done on a small scale (e.g., the "nonproliferation reactor" design concept recently investigated by the Energy Research and Development Administration?)
(6) Are there plans to undertake a systematic comparison of nuclear power generation with other supply alternatives? To what extent and how closely would representatives of the public participate in this comparative assessment?

---

[1] U.S. Office of Technology Assessment. Op. cit., p. 67.
[2] Ibid., p. 72.
[3] Ibid., p. 76.
[4] Ibid., p. 224.

Present and Future Domestic Supply of Geothermal Energy

(By Joseph P. Riva, Jr.*)

In the broadest context, geothermal energy is the natural heat of the earth. The Earth's interior temperature increases inward toward the core, primarily due to natural nuclear decay and the frictional heat of large moving rock masses. Most geothermal energy is too diffuse to be recovered economically, but does have potential economic significance where it is concentrated into restricted volumes which can be considered as somewhat analogous to the concentration of metals into ore deposits or oil into petroleum reservoirs.

The existence of geothermal energy has been known for thousands of years through such phenomena as volcanoes, geysers, and warm springs. Warm springs have been utilized for many centuries as medicinal spas. Geothermal energy was first used to produce electricity in 1904 in Italy, and has been used since the 1930's for space heating in a number of countries of the world. In the United States, it has been utilized for the past 20 years in northern California to produce electric power.

DOMESTIC GEOTHERMAL ENERGY RESERVES AND RESOURCES

The heat of the Earth's interior is one of the largest energy resources available. However, more important than sheer resource size is the extent to which it can be developed with current technology at an acceptable cost and the impact upon its use of institutional and environmental constraints.

There have been a number of estimates of domestic geothermal resource base which differed from each other by several orders of magnitude. This wide variation has been due to a lack of, or differing, assumptions regarding geothermal technology and general economic conditions and also sometimes to an inadequate understanding of the nature and the extent of the geothermal resource itself. Although it is always difficult to predict future technology and economic conditions, progress has been made in the past several years toward a better understanding of the nature of the geothermal resource and thus the basis for an assessment of the magnitude, distribution, and recoverability of the various kinds of domestic geothermal resources is now available. This basic geothermal information was used by the U.S. Geological Survey in 1975 in an assessment of the geothermal resources of the United States. Although the 1975 Survey estimates rest on a much improved scientific base, they cannot be considered as final or as valid indefinitely into the future. They are limited by the data available in 1975 and will need to be revised as more data and better methods of evaluation become known.

*Joseph P. Riva is a specialist in Earth Sciences at the Congressional Research Service.

21-616 O - 78 - 7

The resources of the most attractive identified hydrothermal convection systems (excluding national parks) with predicted reservoir temperatures above 150 degrees centigrade are estimated by the Survey to have an electrical production potential of about 8,000 megawatt-century, or about 26,400 megawatts for 30 years. A megawatt-century of electricity is a unit of energy equivalent to 1,000 kilowatts being produced for 100 years or 3,333 kilowatts being produced for 30 years. Nearly one-half of the above estimation (3,500 megawatt-century or about 11,550 megawatts for 30 years) is considered by the Survey to be recoverable with present prices and technology.[1] These reserves are located in the Western United States and in Alaska and Hawaii. In addition, high temperature resources in undiscovered convection systems are estimated by the Survey to be about five times greater than identified resources and undiscovered vapor-dominated geothermal systems may be as extensive as identified vapor dominated systems. The total energy recoverable with current technology from such undiscovered resources is estimated by the Survey to be about 38,000 megawatt-century (about 125,400 megawatts for 30 years).

All of the intermediate temperature systems (90 to 150 degrees centigrade) are submarginal for the generation of electricity, but under favorable circumstances can be utilized for space heating and industrial purposes. The efficiency of direct use of geothermal energy for heating is greater than for generation of electricity for the same purposes. The heat that can be recovered for local utilization from identified intermediate temperature geothermal resources is estimated by the Geological Survey to total 27,500 megawatt-century (about 90,750 megawatts for 30 years). Undiscovered intermediate temperature geothermal resources are projected to be about three times as large.

The geopressured deposits of the Gulf Coast region are considered by the Survey to have a very large geothermal potential. The mechanical and thermal energy deliverable at the wellhead from geopressured systems in the onshore portion of the Gulf of Mexico assessed by the U.S. Geological Survey varies according to production plan, but is considered likely to range from 9,000 to 35,000 megawatt-century (29,700 to 115,500 megawatts for 30 years). This range does not include the energy from recoverable methane, which may be equal in value, because reliable data are lacking. Other geopressured sections of the Gulf Coast are estimated by the Survey to probably contain at least three times more potential energy than the evaluated part, but recoverable energy could be less because of lower permeabilities expected in the older and more deeply buried sediments. For any one kind of energy considered alone, the geopressured fluids are likely to be marginal, but when all kinds of potential energy are recovered, a small but significant part of the total resource may be considered as reserves, particularly in areas where the adverse environmental impact from exploitation would be low. The unanswered technical questions that remain are whether the geopressured brines contain sufficient natural gas to allow gas production; whether a significant number of individual reservoirs are capable of supporting high-volume hot brine

[1] White, D. E. and William, D. L. Assessment of Geothermal Resources of the United States—1975. Geological Survey Circular 726, Reston, Va., p. 154.

production for extended periods of time; and whether the withdrawal of the geopressured fluids will lead to compaction of the host rocks, loss of permeability, and subsidence. It may be that the energy contained in the geopressured deposits will prove too diffuse for near-term exploitation with current technology under foreseeable economic conditions.

The hot, young, igneous magma systems and some areas of high regional temperature gradients (conduction-dominated environments) provide relatively favorable localities for utilizing the energy of hot dry rocks, providing satisfactory methods of recovery can be developed. The potential resources are huge, but these systems cannot now be considered as geothermal reserves.

DOMESTIC GEOTHERMAL PRODUCTION

The current utilization of geothermal energy in the United States amounts to an installed capacity of about 520 megawatts of electrical power in The Geysers dry steam field of northern California and an estimated total non-electrical utilization of between 15 and 16 megawatts in Oregon and Idaho.[2] Plans call for increasing electrical power production at The Geysers to 1,400 megawatts by 1985. There have been a number of projections of future domestic geothermal energy production. The following table presents a selection of these estimates.

TABLE 27.—DOMESTIC GEOTHERMAL ENERGY PRODUCTION

[In megawatts]

	1985	1990	2000
University of Alaska (1972)	[1] 132,000		395,000
National Petroleum Council (1972)	3,000–19,000		
Bechtel Corp. (1973)	5,000–24,000		25,000–600,000
Project Independence (1974)	4,000	59,000	
U.S. Department of Commerce (1975)	3,000–8,000		
NASA (1975)	8,000		100,000
ERDA-86 (1975)	1,500–6,000		39,000
U.S. Bureau of Mines (1975)	3,000		10,000
FEA (1976)	1,650	6,100	

[1] Potential.

It can be seen from the table that the more recent studies are less optimistic concerning future geothermal energy utilization and tend to converge on just a few thousand megawatts for 1985 and on some few tens of thousands of megawatts by the year 2000. The smaller projections may even be too high as the development of geothermal resources has been slowing down. Progress seems to be impeded primarily by institutional barriers such as leasing arrangements which appear counterproductive; a lack of specific tax and depletion incentives and intangible drilling benefits; and long delays in obtaining governmental permits at all levels. It is possible that Federal incentives such as loan guarantees, depletion allowances, intangible drilling expense write-offs, reservoir investment indemnities, and even direct subsidies may be needed to approach even the more modest projections. Legislation has been proposed in the National Energy Act to

[2] ERDA-86 Definition Report, Geothermal Energy Research, Development, and Demonstration Program. Energy Research and Development Administration, Washington, D.C., October 1975, pp. I–6 to I–9.

extend to geothermal drilling the tax deduction in intangible drilling costs that is now available for oil and gas drilling in order to bring about an equality of tax treatment among similar activities which compete for capital. In addition under the National Energy Plan, the Department of the Interior, the Department of Agriculture, and the States are to be encouraged to make their leasing and environmental review more efficient so as to remove any unnecessary barriers to the development of geothermal resources.

Current Status of Synthetic Fuels From Coal

(By Paul Rothberg*)

ISSUE DEFINITION

The conversion of coal to gas and liquid fuels could supplement the Nation's dwindling reserves of natural gas and oil. Commercial processes for the manufacture of these "synthetic" fuels from coal have been available for over a century. However, the existing first generation technology would produce synthetic fuels at prices higher than those for conventional fuels. Large-scale synfuel plants based on current approaches would pose certain economic, technical, environmental, and regulatory problems that bear consideration. For the last several years, intensive debate has focused on means to promote the orderly development of a synfuels industry. Congress has provided that States affected by development of Federal coal leases will receive increased funds to reduce adverse socio-economic impacts. Research and development efforts directed at improved second and third generation processes have been accelerated. Although several economic proposals including loan guarantees and tax advantages for synfuels have been debated, none has became law. Under present economic and policy conditions, significant synfuels commercialization is not expected in the next decade. Even if Federal incentives for commercialization were offered, production levels by 1990 are projected to be less than 0.5 million barrels of oil equivalent per day and 750 to 1,500 million cu. ft. of gas per day.

BACKGROUND AND POLICY ANALYSIS

Coal Gasification

In the coal gasification process, coal is converted to synthetic gas. Three kinds of such gas are currently being considered for commercial development: high Btu, referred to as substitute natural gas (SNG), which has a heating value of about 1,000 Btu/cu. ft., medium or intermediate Btu, which has a heating value of 300 to 400 Btu, and low Btu, which has a heating value of about 150 Btu/cu. ft. SNG has almost the same chemical and physical properties as natural gas, and they are completely interchangeable.

Substitute natural gas from coal could be used in the Nation's existing gas system, thus reducing shortages in the residential market. Low- and medium-Btu gases are industrial fuels and would be used at or near the site of production. These gases may also be used in gas turbines or combined cycle plants for the generation of electricity.

*Paul Rothberg is an Analyist in Science and Technology at the Congressional Research Service.

Gasification Based Upon Existing Technology

When coal is gasified, it is reacted with steam and/or hydrogen at temperatures greater than 1000° F to form low-Btu gas, which is composed primarily of carbon monoxide and hydrogen. To produce SNG, which has a high heating value, the product gas may be of cleansed of impurities, and then upgraded to the quality of natural gas. During this process, undesirable components in coal, such as sulfur, are converted into forms that can be readily removed. Gasification also removes ash.

Technology for gasifying coal has been successfully demonstrated in several foreign countries. In U.S. markets, the price of the synthetic gas produced by these processes would probably be much higher than that for conventional fuels.

Gasification Based Upon Advanced Technology

Primarily over the last 15 years, the Federal Government and industry have advanced and tested new technologies to convert coal to useful energy products. Several pilot plants that can produce synthetic gas are in operation or under construction. These technologies are based on modified versions of older technology originally used in Europe or on new technology developed in the United States. The Department of Energy (DOE) divides its R&D program into several areas, including high-Btu and low-Btu coal gas.

High Btu Coal Gas.—The DOE program includes several major second-generation pilot projects designed to develop an improved process to manufacture substitute natural gas (SNG). Included in the Department's program is the HYGAS process, developed by the Institute of Gas Technology: the CO_2 Acceptor Coal-Gasification process, developed by the Consolidation Coal Company; the Synthane process, developed by the U.S. Bureau of Mines; and the Bi-Gas process, developed by Bituminous Coal Research, Inc. Many of these projects are funded jointly by the American Gas Association and the Department of Energy (DOE). The Association typically provides one-third of the funding, with the Government providing the rest. The processes under investigation differ substantially from each other. The process most feasible for commercial application still needs to be determined.

The HYGAS process, in which coal reacts directly with hydrogen-rich gases to produce methane, began pilot-plant operation in 1971. In 1974, its steam-oxygen process for generation of hydrogen came on-stream. In May 1975, it ran under self-sustaining conditions and by the end of June it completed experimental runs on lignite. Continuing into 1977, the pilot plant used bituminous and sub-bituminous coals as feedstock. This will provide a data base for scaling up the process for demonstration or commercial purposes.

The CO_2 (carbon dioxide) acceptor pilot plant has been completed and a series of runs appears to have fully demonstrated the technological feasibility of the processes. Most of the major mechanical problems also appear to have been solved.

The Synthane plant emphasizes the production of more methane directly in the gasifier, thus reducing the load in the methanation step. Mechanical construction was completed in June 1975. Currently, the pilot plant is processing agglomerating bituminous coal and operation with this type of coal will continue into fiscal year 1979.

Construction of the Bi-Gas plant in Homer City, Pa., was completed in September 1975. Pilot plant research will run through fiscal year 1979, at which time a decision will be made on future development.

Technologies advanced in this program may, over the long-term, reduce the cost of producing synthetic gas for residential purposes. The program is expected by many to continue until industry can construct, with an acceptable degree of risk, a commercial-size plant based on one or a combination of these processes. The next stage in this program would be the construction and operation of demonstration-sized facilities.

Low-Btu-Coal-Gas.—The generation of low-Btu gas from coal requires a less complex plant than that required for production of high-Btu gas. Consequently, capital and operating costs are expected to be lower per unit of energy. Low-Btu gas systems are much closer to being commercialized than high-Btu plants. Within the next few years, small sized low-Btu gasifiers based on existing technology may be installed at several sites, including a tractor factory in York, Pa.; a steam boiler at the University of Minnesota's Duluth campus; a Pittsburgh, Pa., plant to heat kilns and dryers; and at a housing project in Lexington, Ky. Roger Broeker of Foster Wheeler Corp. says these units are competitive with burning oil and gas.

To advance the current state of technology, DOE is funding several promising new concepts for low-Btu gas generation. Laboratory and pilot plant projects include: fluidized, entrained and fixed-bed gasification systems; molten salt pressurized process; and ash agglomeration. Several projects will be completed by FY 79; however, some are expected to run beyond FY 81.

Outlook for a Coal Gasification Industry

The American Gas Association has recently published a status report on planned commercial and demonstration high-Btu coal gasification projects. This report indicates that many of the interested companies have suspended their projects, have not yet filed with the Federal Power Commission (FPC), have requested deferral of FPC decisions, or have conducted only preliminary feasibility studies. Even though these companies previously expressed serious intentions to operate commercial-sized facilities, construction of the first large scale plant in the United States has not yet begun. Mere interest in commercialization is many steps away from the corporate decision to invest the $1.6 billion to $1.7 billion required for a plant to produce large quantities of gas, such as 250 million cubic feet per day, for residential purposes.

Efforts to commercialize large-scale coal gas plants in the United States have confronted an array of obstacles, including: high capital requirements and uncertainities of regulatory policy. The industry hopes for a supportive Federal synthetic fuels policy. The future of a synfuels industry will depend on several factors, such as its ability to compete in the market place; availability of water, materials, and manpower; willingness of financial institutions to lend the billions of dollars required, and Federal policies affecting this industry.

According to the Synfuels Interagency Task Force, which was used by the Ford Administration to design a program to commercialize synfuels, the outlook for both high-, medium-, and low-Btu gas plants

is limited under existing policy and economic conditions. The task force maintained that the overriding constraint facing this industry was short supply of venture capital. They argued that until there was a positive growth-oriented industrial and financial environment, only limited funds would be spent on future planning by industry. They concluded that significant production of low- or medium-Btu gas from coal in the 1975–1985 time period was unlikely. (The exception to this will be the very small, low-Btu gasifiers discussed above.)

With respect to high-Btu gas plants, the task force maintained that "given the current regulatory climate together with the enormous increases in required investment and the resulting prices . . . [that] in the absence of new Federal initiatives, no commercial development will take place in time for significant production by 1985."

It appears unlikely that commercial plants will be producing as much as 250 million cu.ft. of pipeline quality gas per day before 1985. If existing conditions impacting on synfuels production and marketing are not altered, there may be little or no commercial (large-scale) production of coal-based high-Btu gas by the early 1990's. However, should a favorable climate develop for synfuels production, e.g., Federal loan guarantees, favorable pricing, environmental, and regulatory policies, and available water and construction materials, a slow but gradual growth of a coal gasification industry may be possible.

COAL LIQUEFACTION

Coal liquefaction is the process of converting coal to synthetic liquid products, such as boiler fuels or petrochemical feedstocks. During World War II, the Germans used this technology to supply a large portion of their liquid fuel needs. Industry and Government are now developing modern liquefaction processes. DOE supports pilot plant and laboratory projects to advance three liquefaction processes: solvent extraction, direct hydrogenation, and pyrolysis. These projects are the initial stage in a program leading towards commercialization of new coal liquefaction technology.

Demonstration Plants and Commercial Plans

Coal liquefaction is gradually moving from the pilot plant to the demonstration plant, the second major stage in DOE's effort to advance this technology. ERDA's Fossil Energy Program sought competitive bids to bring its demonstration program to a successful conclusion over an 8-year period. In a comprehensive request-for-proposal to industrial firms and others, the Fossil Energy Program asked for details for a plan to design, construct, and operate a demonstration plant for converting high-sulfur coal into a clean liquid boiler fuel. Subsequently, in January 1975, a $237.2 million contract was awarded to Coalcon Co. of New York, an affiliate of Union Carbide and Chemico, for a coal-to-clean-boiler fuels demonstration plant. Using 2,600 tons of coal per day, the plant was expected to produce 3,990 barrels of liquid and 22 million cu. ft. of synthetic natural gas each day.

Coalcon formed a consortium of private companies and public agencies to support the program. The plant was to be built in New

Athens, Ill. The process used was to be a combined hydrogenation and pyrolysis method that produces gases, liquids and solids. The solids are used for process heat and for producing additional gas. According to a GAO report, the project was plagued by technical and managerial problems from the onset; it failed in its initial phase despite a $10-million cost overrun and a 14½ month schedule slippage. The project was terminated on June 15, 1977.

The Department of Energy has selected the Solvent Refined Coal (SRC) process for advancement in a new demonstration project. Under existing market and Federal policies, it is unlikely that any company would build a commercial-sized coal liquefaction plant within the next five years.

Without Government incentives, commercial production of synthetic liquids from coal is projected to be zero through 1985, and possibly until 1990 or beyond. First generation technologies would produce products only at price levels well above those expected to represent future world price levels for oil.

Concerns Associated with Development of a Synthetic Fuels Industry

The development of large-scale synfuel plants could result in the following technical, environmental, and regulatory problems.

Technical Concerns.—The size envisioned for a commercial synfuels plant in the United States is enormous. Industry commonly talks about a plant producing from coal 50,000 barrels of liquid fuel and 250 million cu. ft. of gas per day. Worldwide experience in building synfuel complexes is rather limited. Construction of the huge plants envisioned in the United States could result in many technical uncertainties and material shortages.

With respect to coal liquefaction, many would argue that second generation direct liquefaction technology is not ready for commercialization. Considerable development and demonstration work remains to be done on advanced liquefaction technology.

Socioeconomic and Environmental Concerns.—Many environmental problems associated with synfuel technologies are common to other processes that require coal. Among these are health and safety aspects of coal mining, reclamation of strip-mined lands, allocation of scarce water resources (especially in the West), and pollutants and particulates emitted to the environment. Compared with a conventional coal-fired power generating system, a coal gas plant is expected to consume less water and to emit less air emissions into the environment; that is, a coal gas plant is expected to emit less particulates, sulfur dioxide, nitrogen oxides, carbon monoxide, and hydrocarbons.

A synthetic fuels industry in the West may impact on small and relatively poor towns or Indian reservations. During construction of this industry, it is feared that "boom towns" would be created. Under such conditions, local service institutions would not be able to handle increased populations associated with synfuel projects. Care and planning would facilitate reduction of the adverse effects of boom/bust cycles. The Congress has already taken some action to reduce the social and economic impacts of coal development. In the Federal Coal Leasing Amendment Act of 1975 (P.L. 94–377), the Mineral Lands Leas-

ing Act was amended so that an additional 12½% of all moneys received from sales, bonuses, royalties and rentals of certain public lands (including Federal coal and oil shale deposits) shall be returned to the State within the boundaries of which the leased lands or deposits are located.

Financial and Economic Concerns.—High-Btu synthetic gas from coal may cost about \$3 to \$4.5 per thousand cu. ft., which would be uncompetitive with new, interstate gas that sells for about \$1.45 per thousand cubic feet, under current Federal regulation. Oil from coal will probably cost more than \$25 per barrel, which would be uncompetitive with the current world price of about \$13–\$14 per barrel. Some forecasts predict that the prices of the synthetic fuels will become competitive around 1990. Before that time, the partisans of accelerated development of synthetic fuels must deal with a financial community that is dubious about financing an industry whose product is unlikely to be competitive. Many advocates of synfuels development argue for Federal economic incentives to stimulate commercialization.

Firms interested in substitute natural gas have complicated finances since they are usually regulated utilities. Compared to the major oil firms, their capitalizations are small, about \$1 billion, and their indebtedness is limited to a certain percentage of their assets. Thus, in order to commercialize coal gas plants, advocates note that consortiums may have to be formed and maintained in the face of much uncertainty.

The financial community is also concerned that a huge amount of capital must be formed and devoted to the energy market as a whole if the country's energy goals are to be met. It is generally agreed that the economy can generate enough capital, but it is not clear that devoting a large portion of this capital to developing synthetic fuels will best serve the country's overall needs and goals.

Regulatory Concerns.—Construction and operation of synthetic fuel plants is governed by a large array of environmental and regulatory constraints. Numerous regulations affect land, air ,and water use, and meeting them adds to the time and costs associated with the plants. In addition to the frustrations induced by this situation, a common fear of the participating firms is that once the requirements are met, someone will change them. A great desire of industry is a stable, predictable regulatory climate.

Both public utilities and interstate gas pipeline companies are interested in synthetic gas. The rate structures of these companies are determined by Federal and State laws. Regulatory decisions may affect the attitude of the investment bankers toward lending money to these ventures.

Outlook and Constraints for Shale Oil Production

(By Paul Rothberg*)

ISSUE DEFINITION

Oil shale is an abundant energy source, but is unlikely to contribute significantly to U.S. energy supply before 1985. Associated with the exploitation of this resource are many unresolved issues, such as the role of the Federal Government in its development, environmental consequences of a large-scale oil shale processing industry, social and economic planning related to this industry, future leasing policies of the Department of the Interior, price supports, loan guarantees, or contract provisions for shale oil, tax policies related to oil shale development, and the establishment of a comprehensive national oil shale policy (possibly as part of a national energy policy). Under current economic and policy conditions, shale oil production could reach 20,000 to 57,000 barrels per day by 1985.

BACKGROUND AND POLICY ANALYSIS

The 1973–1974 oil embargo stimulated renewed interest in the development of new sources of energy. Analyses indicated that exploitation of oil from shale could provide a supplemental and secure liquid petroleum and gas source that would, in turn, reduce dependence upon imports from foreign countries and contribute favorably to the U.S. balance of trade. Shale oil production could also yield large quantities of the following byproducts: sulfur, ammonia, alumina, soda ash, nahcolite, and petroleum gases.

Two major methods for exploiting oil shale resources are:

(1) Conventional mining (either deep or surface mining), coupled with surface processing of oil shale. Surface processing involves a sequence of three basic steps—mining, crushing, and retorting (heating) of shale—to produce gas and/or oil. Advanced surface processes include: Paraho, TOSCO–II, Union Oil Company's processes, and Superior Oil Company's process. All these technologies have been tested on a smaller than commercial scale, at either the pilot or demonstartion scale.

(2) In situ or underground processing of shale. Instead of retorting above ground, shale oil and gas may be produced underground, or in situ (in place). Occidental Petroleum Corporation has tested a modified in situ technology.

OUTLOOK AND CONSTRAINTS

Production from these technologies could, under current economic and policy conditions, reach 20,000 to 57,000 barrels per day by 1985.

*Paul Rothberg is an Analyst in Science and Technology at the Congressional Research Service.

This quantity of oil would be insignificant when compared to current U.S. oil requirements of roughly 18 million barrels per day. Even when a commercial oil shale industry emerges, its growth is expected to be slow and gradual.

Over the last 60 years, the emerging oil shale industry has gone through several periods of boom and bust—mostly bust. Since the Arab oil embargo of 1973–1974, industry's plans to commercialize shale projects have generally been delayed or suspended. Progress on all four tracts of the Federal Prototype Oil Shale Leasing Program (discussion follows) was halted for a year because of environmental uncertainties and other problems. To date, commercially related activities have commenced again on the two prototype tracts in Colorado, though companies on the two tracts in Utah are not proceeding with their plans because of legal uncertainties. Superior Oil Company, which has advanced a unique processing technology and owns some shale lands in Colorado, has delayed developing a commercial facility until a land exchange with the Department of the Interior can be consummated. Superior is seeking a better land arrangement for its mining scheme. Colony Development Operation has suspended plans for commercialization on its privately held lands in Colorado.

The emerging U.S. oil shale industry confronts many difficulties, uncertainties, and problems. Estimated construction costs for above ground retorting (heating of shale to produce oil) have quintupled over the last 5 years, from approximately $250 million to $1,250 million for a 50,000 barrels per day above ground facility. The economic feasibility of some processing technologies is uncertain and commercial scale projects still have to be proven environmentally acceptable and economically feasible. Lester Shramm, of the U.S. Bureau of Mines, suggests that a principal deterrent to above ground commercial production is the lack of economic incentives. He writes in Mineral Facts and Problems, that "the risk/reward relationship protrayed by economic analyses based on estimated costs does not appear favorable enough to attract venture capital in the large amounts needed, unless additional incentives are provided and uncertainties about shale oil's access to free markets are resolved."

The exploitation of oil shale resources threatens to create numerous environmental impacts, such as huge amounts of spent shale, mining waste products, water consumption, water and air effluents, and other land impacts. Many environmentalists are vehemently opposed to development of this resource. Local communities and State governments are particularly sensitive to the social and economic impacts associated with development of energy resources in the West. Companies seeking to operate shale facilities must obtain numerous environmental permits and approvals. Federal, State, and local environmental requirements and standards have constrained and probably will continue to limit efforts to commercialize oil shale technologies.

Uncertainties concerning Federal economic, environmental, and legal policies are also affecting the emerging oil shale industry. One of the questions is whether and when will Congress authorize loan guarantees and other economic incentives to promote shale development. Other questions include: How will new Federal environmental regulations affect processing operations? Are pre-1920 mining claims

on Federal property valid? Will special tax credits for shale oil be allowed?

Of the factors dissussed above, no single constraint can be identified as the major factor limiting commercialization of the oil shale industry. It is the combination of factors and their synergistic effect, that is likely to keep the contribution of shale oil to the U.S. energy supply at a low level for at least the next 10 years.

RESOURCE BASE

The western U.S. (Colorado, Utah, and Wyoming) oil shale higher grade resources contain the equivalent of about 600 billion barrels of oil—roughly equal to the known world reserves of oil. If the lower grade resources are added, the resource base of the western shales is about 2 trillion barrels of oil—more than 50 times the total U.S. reserves od petroleum. Competitive in situ (underground) and deep mining technologies may make possible the recovery of a much larger portion of the 2 trillion barrels of western shale oil resources, which include low- and medium-grade shales. The Federal Government is by far the major owner of western shale oil resources.

"Eastern" or "Central" gas shales have been located in Ohio, West Virginia, Pennsylvania, New York, Kentucky, Michigan, Indiana, Illinois, Virginia, Tennessee, Mississippi, and Alabama. Columbia Gas System Supply Co. estimates that about 285 trillion cu. ft. of producible gas lies beneath Ohio, West Virginia, Pennsylvania, Kentucky, and New York. Increased funds for R&D on eastern shales may allow expanded work on chemical characteristics of oil shale and shale oil, in situ processing, and basic support work. The U.S. Geological Survey, Department of the Interior, has initiated on behalf of DOE a 5-year program to assess the gas potential of black shales of Devonian age that underlie an area of more than 160,000 sq. mi. in the Appalachian basin. The processing of Eastern oil shales is being researched under a contract by Dow Chemical Company and the Michigan Energy Resources Research Association.

The Secretary of the Interior has the responsibility for leasing and managing the publicly owned oil shale lands. Leasing policies for these deposits have an important bearing on the rate of development of this resource, because 72% of the U.S. shale lands, containing nearly 80% of the total quantity of shale oil, is federally owned.

MAJOR ACTIVITIES

Until recently, the federally owned oil shale deposits were not available for private exploitation. During the early 1970s, the Department of the Interior established the Federal Prototype Oil Shale Leasing Program, which was intended to provide a quantitative evaluation of environmental impacts, as well as prove several technologies, and provide cost and economic data. Six tracts of land (two each in Colorado, Utah and Wyoming) were offered for lease. The highest bids accepted were $210 million for tract C–a in Colorado, $117 million for tract C–b in Colorado, $75 million for tract U–a in Utah and $45 million for tract U–b in Utah. No bids from industry were received on the two oil shale tracts offered for lease in Wyoming.

Preparation of detailed development plans and collection of environmental baseline data have been major activities on Colorado tracts C–a and C–b, and on tracts U–a and U–b in Utah. The following paragraphs describe briefly some of the activities on these tracts.

On Colorado tract C–a, the Rio Blanco Oil Shale Project has collected extensive geotechnical and environmental data to establish baseline conditions on and around the tract. These studies also provide input to engineering analysis which will be useful in the selection of mining and processing plans for development. Investigations have included work on mining, engineering, hydrology, geology, community planning, soils, overburden, and revegetation. The Department of the Interior has approved Rio Blanco's plans to begin development of tract C–a by the modified in situ processing. The plan projects to intermittent production of shale oil at about a 1,500-barrel-per-day production level. Some shale oil is expected to be recovered by above ground processing. These companies plan to spend $93 million for 5-year developmental programs.

At Colorado tract C–b, investigations have been conducted on surface water, core drilling and associated ground water, air quality, fish and wildlife management, revegetation, archeological studies, and scenic values related to tract C–b. These studies have been reviewed by the Oil Shale Environmental Advisory Panel of the Department of the Interior, which examines aspects of the Federal Prototype Oil Shale Leasing Program. A detailed development plan on tract C–b has been submitted and approved by the Department of the Interior. This tract is expected to be developed using a modified *in situ* technology advanced by Occidental Petroleum Corporation. Ashland Oil, Inc., and Occidental Petroleum Corporation now hold the lease to tract C–b. These companies plan to spend $440 million to develop a plant capable of producing 57,000 barrels per day by 1983. The costs of the shale oil produced from this plant may be competitive with world oil prices.

Planning for the development of tracts U–a and U–b is being done on a cooperative basis. The three companies involved in these tracts, Phillips Petroleum Company, Sun Oil Company, and Sohio Petroleum expect that the U–a and U–b project, called the White River Shale Project, will become a three–company equal ownership situation. The project is located in Uintah County, about 40 miles south of Vernal, Utah. Full-scale production of the tract may be between 50,000 and 100,000 barrels/day. Reports summarizing environmental baseline data collection and monitoring programs (including water, air, biological resources, geology and soils, historic and scientific resources, revegetative studies, geologic exploration, and aesthetics) on combined tracts U–a and U–b have been reviewed by the Oil Shale Environmental Advisory Panel.

The White River Shale Project has postponed its commercial plans, partly because of clouded title to the land and uncertainties as to the future of air pollution standards in Utah. A summary of selected major oil shale activities is presented in Table 28.

TABLE 28.—SELECTED MAJOR OIL SHALE DEVELOPMENT ACTIVITIES [1]

Project and companies	Planned technology	Completed by or 1st test by--	How much shale oil	Expected cost of activity
Prototype oil shale leasing program, tract C–b; Ashland Oil, Inc., Occidental Petroleum Co.	Modified in situ	1983 completed	Planned 57,000 bbl/d	$440,000,000.
Department of Energy—Occidental Petroleum Co., cooperative demonstration plant program.	Modified in situ	Around 1982	2,500 bbl/d	$60,500,000.
Prototype oil shale leasing program, tract C–a, Rio Blanco oil shale project; Standard Oil Co. of Indiana, Gulf Oil Corp.	Modified in situ	1979 1st test, work towards commercialization after 1981.	Intermittent production of demonstration unit.	Planned expenditure of $93,000,000 over the next 5 yr.
Colony Development Operation; Atlantic Richfield Co., TOSCO—formerly Oil Shale Corp.	Above ground retorting, using TOSCO II system.	Commercial plans held in abeyance.	About 47,000 bbl/d	About $1,200,000,000.
Union Oil Co. of California	Above ground retorting, using Union's process.	No recent information.	About 7,200 bbl/d pilot plant.	Considering investment of $123,000,000.
Paraho Development Corp.; about 17 oil and industrial companies have participated in this project.	Above ground retorting, using Paraho process.	Pilot plant tested, semiworks projects operating and producing 180 bbl/d.	4,000 to 5,000 bbl/d modular unit.	Planned investment of $65,000,000.
Superior Oil Co	Above ground retorting, using Superior's 3 mineral process that yields shale oil, alumina, and sodium minerals.	Pilot plant tested, awaiting land exchange deal with Department of the Interior.	13,000 bbl/d	Investment of $300,000,000.
Prototype oil shale leasing program, tracts U–a and U–b, White River oil shale project; Sun Oil Co., Phillips Petroleum Co., Standard Oil Co., of Ohio.	A combination of modified in situ and above ground retorting.	Plans suspended pending outcome of legal problems.	100,000 bbl/d	$1,610,000,000.

[1] Data represents published plans, expectations, and costs.

Energy From the Oceans

(By Robert E. Morrison*)

The United States, confronted with an increasing demand for energy, is obliged not only to seek proper exploitation rates for energy resources now being tapped but must also search for alternate sources of energy. In this connection, renewable sources of energy from the ocean offer some promise for augmenting our conventional energy sources and for reducing dependence on imported fuels.

Among the potential sources of renewable energy from the oceans are ocean thermal energy conversion (OTEC), tides, waves, currents, and salinity gradients. These sources have the particular advantages that they are essentially environmentally clean and that there are no fuel costs, since capture of this energy occurs at intermediate stages in the natural dissipation of solar and gravitational energy. The chief disadvantages at present in harnessing these resources stem from their variability in time and location, from technical problems requiring further engineering research and development, and from their present borderline or unfavorable economic position compared with that of other kinds of energy now available. Thus, although the concept of tapping the power in the oceans is intrinsically attractive and technically feasible, there remain problems to be solved in converting this potential energy into a marketable commodity for modern use.

Singly or collectively, these sources of energy when fully developed could supply only a portion of our energy requirements. Their contribution can be proportionately much greater, however, in localities adjacent to which local conditions make the siting of particular kinds of ocean energy conversion plants especially advantageous.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

The operation of an OTEC power plant depends on the natural temperature differences which exist over much of the world ocean between the warm surface layer and the colder deep sea. The surface waters absorb solar energy and serve as a natural energy collector and storage system, permitting the continuous conversion of thermal energy, unlike other solar schemes which require some form of storage to smooth out diurnal-nocturnal or seasonal variations.

The minimum required vertical temperature difference from surface to deep ocean for operation of an OTEC system is about 17 centigrade degrees; hence locations for deploying such systems are limited in geographical extent, especially since for many applications it is desirable to site the plant reasonably close to land. The best OTEC locations worldwide, providing optimum temperature differences

*Robert E. Morrison is a specialist in Ocean Policy at the Congressional Research Service.

over minimum vertical spacing, are found in the latitude belt between 10° N and 10° S, although suitable areas may also be found up to 20° N and 20° S and even beyond, depending on local oceanic conditions. The most promising areas for the United States are in the Gulf Stream off the southeastern U.S. coast, the Gulf of Mexico, the vicinity of Puerto Rico and the U.S. Virgin Islands in the Caribbean, and the Hawaiian Islands and other U.S. possessions in the Pacific.[1]

An OTEC plant can be operated in a "closed" or "open" cycle. In the latter, seawater is the working fluid. Warm surface water, evaporated under a partial vacuum, is used to propel a turbine, after which it is cooled in a condenser by cold seawater which is pumped from the deep ocean. In the closed system the warm surface water is pumped through a heat exchanger in order to evaporate a working fluid, such as ammonia or propane. The vaporized fluid drives a turbine and is then condensed through heat exchange with cold seawater. The working fluid is then returned to the evaporator for re-use in the cycle. Although there is no fuel requirement for the basic operation of OTEC, large quantities of water must be pumped because of the relatively small temperature differences; consequently, the net power of the system is reduced by pumping power requirements.

The principal applications of OTEC are in the production of electrical power and of energy-intensive products such as chemicals, fuels, and metals. Supplemental applications include the production of fresh water and the promotion of aquaculture through the nutrient supply from circulated deep ocean water. A variety of studies have shown that OTEC power plants in the range of 100 to 1,000 megawatts have commercial applications for transmission of electricity to shore and for chemical processes.[2] It is apparent from such studies that costs of energy and materials produced from OTEC can be made competitive with those of fossil fuels and nuclear energy.

The OTEC concept appears technically feasible, and the closed-cycle option now seems to be preferable. In order to assure the technical and economic feasibility of OTEC further intensive engineering development is required. A prime area for such development is in the design and construction of heat exchangers, the single most important element of the system. Other important research considerations include techniques for controlling biofouling and corrosion, development of an optimum working fluid, and development of suitable hulls or platforms. Research in these and other problem areas is being sponsored in the OTEC development program of the U.S. Energy Research and Development Administration (ERDA).[3] ERDA plans include development of a 25-megawatt experimental prototype OTEC plant by the early 1980's and operation of a commercial demonstration plant, generating about 100 megawatts, by 1985.[4] There have been estimates that OTEC plants could produce as much as 4 to 10 percent of U.S. power needs by the year 2000.[5] However, since there is no

---

[1] Justus, John R. Renewable Sources of Energy from the Ocean. In Martha Kreebs-decker, Basic Service Research Needs in Energy Technologies. Library of Congress, Congressional Research Leital. , TP 360, 76-81, Apr. 20, 1976, p. 180.

[2] U.S. Energy Research and Development Administration. Ocean Thermal Energy Conversion (OTEC): Program Summary, October 1976. ERDA—76/142, Washington, D.C., p. 1.

[3] Ibid., 115 p.

[4] Ibid., p. 15.

[5] Report of the National Planning Conference on the Commercial Development of the Oceans. (Sponsored by the U.S. Department of Commerce, the U.S. Department of the Interior, and the U.S. Energy Research and Development Administration). Warrenton, Virginia, June 9-11, 1976, Volume 2, p. 83.

21-616 O—78——8

domestic system now in operation, such projections are highly speculative.

TIDAL POWER

Tidal action is unceasing and predictable, and the supply of energy from the tides is inexhaustible. The total power worldwide in ocean tides is about one million megawatts; however, by a conservative estimate, only about 13,000 megawatts [6] can be exploited, because of the need to locate tidal power plants on estuaries and embayments where energy extraction is technically feasible today. Although the total useful power in the tides is relatively small, tidal power plants at advantageous sites may provide power to augment that of other energy sources in a significant way in particular local coastal regions.

Tide mills have been in operation for centuries. As early as the eleventh century tidal power was used in Europe for grinding grain, and in the eighteenth and early nineteenth centuries such mills were also built in the United States, particularly in New England. These elementary tidal plants became obsolete, however, with the arrival of inexpensive electricity produced by hydroelectric and thermal generating plants. Interest in modern tidal plants for generating electricity was initiated in the 1920's, especially in France, the country which has been in the forefront in twentieth century tidal energy development.

Modern tidal power plants are in operation in France, the Soviet Union, and China. Best known of these is the French 240-megawatt Rance River tidal power project near St. Malo, which was completed in 1966. The Russians have built a 400-kilowatt experimental tidal plant at Kislaya Guba Bay near Murmansk and have plans for further development of tidal power. In a recent comprehensive study sponsored by the U.S. Energy Research and Development Administration (ERDA),[7] it was reported that in China 40 small tidal plants were completed in 1958 and 88 were under construction at that time; the total capacity of all these plants was 7,638 kilowatts. Whether the Chinese have built additional plants in recent years is not known.

Worldwide locations which are suitable for siting tidal power facilities are the Bay of Fundy, Canada; the Gulf of California, Mexico; the Gulf of San Jose, Argentina; the Gulf of Mezan and Sea of Okhotsk, USSR; the Bay of Mont St. Michel, France; Walcott Inlet and Secure Bay, Australia; Chientang Kiang Estuary, China; Inchon Bay, South Korea; and the Severn River Estuary and Solway Firth in the United Kingdom. The most promising locations for tidal power plants in the United States are in Passamaquoddy Bay, Maine, and Cook Inlet, Alaska.[8]

The tidal forces between the Earth and the Moon and Sun shift large quantities of ocean water over the surface of the earth. In estuaries and embayments this periodic shift produces flood and ebb currents which follow, respectively, the rise and fall of the sea nearby. Depending on the geometry of the estuary, the effects of the tide can be dramatic at some locations, with tidal ranges greatly amplified within the estuary.

[6] Lawton, F. L. Time and Tide. Oceanus, v. 17, summer 1974, p. 30.
[7] Wayne W. W., Jr. (study director). Final Report on Tidal Power Study for the United States. Stone and Webster Engineering Corporation, Boston, March 1977, volume 1, p. 2-2.
[8] Ibid.

The power capacity in a hydroelectric system depends on the volume of water flowing and the head or height through which the water drops. Generally, the head and water volume associated with the tides are both relatively small compared with those of hydroelectric projects.[9] Extraction of energy from a tidal estuary is accomplished through the controlled filling and emptying of basins, formed by damming portions of the estuary, as the tide passes through its flooding and ebbing cycle.

Although rather complex schemes have been devised for harnessing tidal energy, there are generally two basic configurations—the *single-basin* and the *double-basin* schemes. Single-basin arrangements may involve generation of electricity as water passes through turbines on the ebb tide, the flood tide, or both. The operation is termed "single effect" if flow is used in one direction only; if generation is in both directions, it is referred to as "double effect" operation. The double-basin configuration requires two adjacent pools, one operated as a "high pool" and the other as a "low pool," between which are located the turbines. This arrangement permits power generation continuously, although about half of the available energy is sacrificed. The high pool is filled by the flood tide and is drained into the low pool during the ebb tide. There are variations of both the single- and double-basin schemes, whereby during power generation water is also pumped into storage basins. The head of water in the storage basins can then be used to operate turbines during the period when power would not ordinarily be generated or to augment the generated power during peak periods.

For any tidal plant, the lower the mean tidal range, the greater is the overall cost of the project. A tidal range of about 7 meters (23 feet) is generally considered as the required minimum for economic generation of electrical power. Furthermore, the average cost per kilowatt for turbogenerators and other equipment increases as the rated capacity of each unit is reduced. For example, for a given head of 13.2 feet, a 2-megawatt reversible turbine costs about $1,500 per killowat installed, while a 12.5 megawatt unit costs only $750 per kilowatt installed.[10] This equipment cost differential and the greater savings in construction costs per kilowatt make larger tidal power projects more economical than smaller ones, other conditions being equal.

In the United States there are only two regions with sufficiently large tidal ranges and suitable tidal basins for development of major tidal power facilities. These are the Cook Inlet in Alaska with a mean range of 18.2 feet and the Passamaquoddy Bay region in Maine with a 25.1-foot range. The total developable power in these two regions is about 4,500 megawatts installed capacity, with an annual energy output of 18.3 billion kilowatt-hours—less than one percent of U.S. total electricity production for 1976.[11]

Although the Cook Inlet region has a greater power potential than the Passamaquoddy region, the recent ERDA study determined that, owing to technical problems associated with design, construction, and operation as well as environmental considerations, the Maine site is preferred at this time for major tidal power development. Com-

[9] Smith, F. G. Walton. The Seas in Motion. New York, Thomas Y. Crowell Co., 1973. p. 229–231.
[10] Wayne. Op. cit., p. 2–4.
[11] Ibid., p. 2–4 and 2–5.

parison of power-generation options currently available in New England showed that such a plant is "attractive," especially since anticipated rises in fuel costs will compensate for the initial high investment costs in the tidal plant.[12]

WAVE POWER

The ocean acts as a giant collector and integrator for energy in the winds which blow over it, sometimes with high variability. Energy thus collected is delivered by the wind-generated sea surface waves to distant shores, where wave-energy conversion facilities could intercept and transform this energy into electricity or some other energy form, augmenting other energy sources. Though at any given time the total wave energy in the oceans is estimated at 300 trillion kilowatt-hours, it is clear that only a fraction of this energy can be technically exploited since it is diffusely distributed, its magnitude is low or highly variable in some world areas, and capture of this energy is most advantageous at facilities located adjacent to populated coastal areas.

The United Kingdom is particularly well-situated for intercepting reasonably high-intensity, low variability ocean wave energy as it is carried to its coasts, and it has been predicted that, before the close of this century, about one-half of that country's electricity needs could be provided through the conversion of wave energy along a stretch of coastline between 600 and 1400 miles long.[13] The United Kingdom has launched the most comprehensive development program in support of the energy potential from ocean waves. Other countries with some potential for wave energy and an interest in its development include the United States, Japan, France, Germany, Sweden, Finland, Norway, and Canada.

The most promising area for wave energy development in the United States in in the Pacific Northwest, where the total wave power received along the Oregon-Washington coast reaches a maximum in March of 120,000 megawatts.[13a] Wave power must be shown to be economically sound for this region before its value can be anticipated for other areas of the U.S. coast which are more poorly endowed with this resource.

Although no large-scale wave power plant has yet been developed, extraction of energy from the waves is not a new concept. A number of intriguing concepts have been designed and tested; however, until recent interest in harnessing waves for large-scale power requirements, such converters were designed for low power applications, such as powering navigational devices, and the maximum power of any operating device has been about one kilowatt. In Japan a series of low power wave converters are in use and are available commercially.

Wave energy converters in use, those which have been tested, and those under development have been designed to operate by a variety of physical principles. Some use the onrushing water from breaking waves to fill a storage basin, from which water returning to sea level

[12] Ibid., p. 2-11.

[13] Leishman, J. M. and G. Scobie. The Development of Wave Power: a Techno-economic Study. U. K. Department of Industry. National Engineering Laboratory. Report no. EAU M25, 1976, p. 46.

[13a] McCormick, Michael E. Salinity Gradients, Tides, and Waves as Energy Sources. In Jerome Kohl (ed.). Conference Proceedings: Energy from the Oceans—Fact or Fantasy? January 27-28, 1976. Raleigh, N.C. Coastal Plains Center for Marine Development Services; U. of North Carolina Sea Grant Program; North Carolina State University Center for Marine and Coastal Studies; NCSU Div. of Continuing Education, Industrial Extension Services. Report No. 76-1, UNC-SG-76-04. p. 34.

activates a turbine. There are a number of pneumatic and pumping devices in which the motions of the sea are used to force air or water through turbines. A large variety of interesting and ingenious schemes have been proposed for translating the rise and fall or the changing slope of the sea surface directly into mechanical motions which can drive generators. Further significant development is required, however, if any of these principles are to be incorporated into a system which can provide a significant share of the power needs of a large population or of a major industrial facility.

The rough cost estimates made in the few economic studies to date on wave energy indicate that costs would not be so low as to make wave energy overly attractive at present; however, costs are not so absurdly high as to discourage further development. Since fuel costs are zero, economic feasibility depends primarily on capital investment and on costs for maintenance and replacement. Estimates of installed power costs for the United States have ranged from an optimistically low $450 per kilowatt[14] to thousands of dollars per kilowatt. For the most favorable locations in the United States, the total cost of wave energy is estimated at about 40 mills per kilowatt-hour, assuming a 30-year lifetime for the facility.[15]

POWER FROM OCEAN CURRENTS

A potentially valuable and environmentally sound approach to meeting a portion of our future energy needs is through extraction of energy from ocean currents. Such energy capture is practical in only a few ocean areas, however, where currents are concentrated into relatively narrow, high speed flow, such as the Gulf Stream or other boundary currents, and through narrow passages between land restrictions. Thus, while the total power in ocean currents is estimated at about 5 million megawatts,[16] only a small fraction of this can be converted to a useful form. This site specific nature of usable power in ocean currents is not always a great disadvantage, however, since conversion facilities in these locations may often be near high population centers in coastal areas where transmission problems are simplified.

No major facility exists today for harnessing energy from ocean currents; however, the required technology exists for development of ocean current power conversion without major new breakthroughs. Most schemes for collecting this energy would incorporate some type of turbine or underwater "windmill"; however, devices so used would need to be very large, with blades perhaps as large as 60 meters and with enormous supporting structures. This follows from the relatively low equivalent hydraulic head resulting from the low current speeds, compared with the channeled flow through turbines in a conventional hydro-electric plant. Studies to optimize the design, construction, and positioning of such turbines are required as an augmentation of present turbine technology and hydro-electric applications.

---

[14] Nath, John H., and Richard M. Williams. Preliminary Feasibility Study for Utilization of Water Wave Energy. Wave and Salinity Gradient Energy Conversion Workshop Proceedings. Newark, Delaware, May 24–26, 1976. U.S. Energy Research and Development Administration Report No. COO–2946–1. p. I–27 to I–31.

[15] Ibid., p. I–33 to I–35.

[16] Isaacs, John D. and Richard J. Seymour. The Ocean as a Power Resource. International Journal of Environmental Studies, v. 4, no. 3. March 1973, p. 201.

Present costs for installation of an energy conversion facility in an ocean current would be excessive. Such a facility, using some kind of turbine configuration, and developing about 1,000 megawatts, could be installed in the Florida Current between Miami and Bimini.[17] Depending on the kind of support chosen, the capital cost for such a facility today could be as high as $2,500 per kilowatt capacity.

Although the Florida Current offers the most optimistic prospect for ocean current energy capture, other U.S. areas with some promise include one of the Aleutian passages and some of the tidal rivers along the coast of Maine.[18] Other potential locations outside U.S. waters for possible current energy conversion include the Kuroshio off Japan, the Agulhas Current off the southeast coast of Africa, the Strait of Gibraltar, and some tidal passages off the western coast of France.

SALINITY GRADIENT POWER

When a semi-permeable membrane is placed between waters of differing salinity, a pressure gradient is developed across the membrane which causes the lower salinity water to pass through the membrane to the high salinity side. This pressure is called "osmotic pressure," and the equivalent difference in "head" thus created between waters of differing salinity can be the basis for power generation.

The salt concentration in the oceans varies from place to place and also with depth. The most striking salinity change (or gradient) occurs at the mouths of estuaries, where fresh river water meets and mixes with the saline ocean water. For many years it has been recognized that a large unused source of energy exists at this fresh water-salt water interface. There have been no extensive attempts, however, to develop this salinity gradient power that is available where fresh water rivers flow into the sea. In addition to the mouths of rivers, other possible locations for salinity power plants are hypersaline sinks, such as the Dead Sea or brine pools along desert coasts, used in conjunction with nearby less saline sea water or river water.

Although a number of schemes have been conceived for conversion of salinity gradient pressures into useful power, there are basically two classes of concepts which are of most probable practicality. In most proposed devices, the osmotic pressure difference is converted into a usable form of mechanical energy through the operation of turbines, which in turn operate generators. Another class of conversion schemes would employ direct electrochemical conversion, using dialytic or reverse-electrodialysis cells. Before salinity gradient power can become a technical and economic possibility many problems must be overcome. Among these are the development of improved and much less expensive membranes as well as other materials to be used. The practical design of the configurations of operational salinity gradient energy conversion facilities must also be undertaken.

---

[17] von Arx, William S., Stewart B. Harris, Jr., and John R. Apel. The Florida Current as a Potential Source of Useable Energy. In Harris B. Stewart, Jr. (ed.). Proceedings of the MacArthur Workshop on the Feasibility of Extracting Useable Energy from the Florida Current. Palm Beach Shores, Florida, February 27–March 1, 1974. p. 95.

[18] Heronemus, William E. Alternate Energy Sources from the Oceans. Marine Technology Society Journal, v. 8, no. 2, February 1974, p. 36.

The salinity power that theoretically is available from the global runoff of fresh water into the oceans is coincidentally about equal to the worldwide theoretical potential of hydroelectric power. This same proportion holds approximately true for the United States, where there is not much possibility for increasing the nearly fully realized hydroelectric capacity, which now provides about fourteen percent of our electrical power. Consequently, the maximum theoretically achievable salinity power contribution for the United States is about this same percentage.[19]

[19] Wick, Gerald L., and John D. Isaacs. Utilization of the Energy from Salinity Gradients. Wave and Salinity Gradient Energy Conversion Workshop Proceedings. Newark, Delaware, May 24-26, 1976. U.S. Energy Research and Development Administration Report No. COO-2946-1. p. A-3 and A-4.

SOLAR ENERGY

(By J. Glen Moore)*

INTRODUCTION

A basic premise of the Federal energy effort is that some future reliance on new or previously under-used sources of energy will be necessary to help fill the widening gap between U.S. energy demand and supply. In the face of growing concern for the environmental consequences of nuclear and fossil fuel power generation, "clean" sources of energy are sought. Solar radiation, in principle, is such a "clean" source which can help fill the energy gap. Indeed, it is one of the few energy options available with the potential to provide very large amounts of uninterruptible, essentially pollution-free power for the duration of mankind.

The substitution of solar energy for presently used fuels is not without its problems, however. Solar is a diffuse and intermittent power source. Its collection and storage can lead to very high hardware costs. In fact cost has been the principle obstacle to the widespread use of solar conversion technologies. If solar is to make a meaningful contribution to the U.S. energy demand over the next several years, the cost of collection, conversion and storage must be made competitive with fossil and atomic power systems.

SOLAR TECHNOLOGIES

An attractive feature of solar energy is that it is available in a number of forms which can be tapped to provide useful energy in a variety of ways. With hardware that in most cases is technically proven but not now cost competitive with conventional energy sources, solar energy can be converted to electricity or to clean renewable fuels, or it can be collected and used directly for such purposes as the heating and cooling of building space.

Electric power generation.—The conversion of solar energy to electricity is accomplished by four distinct technologies:

Solar thermal conversion—In solar thermal conversion, solar energy is collected as high-temperature heat, generally by means of mirrors or lenses that track the motion of the sun and direct a concentrated solar flux onto a receiver. Temperatures up to 500° C can be generated by this means, high enough to produce steam at pressures for use in modern steam turbines to generate electricity.

Photovoltaic conversion—Photovoltaic conversion is a non-thermal process for the production of electricity directly from solar energy. Direct solar radiation is used to create electrical charges in a semiconducting material such as silicon, and the charges are then collected

*J. Glen Moore is an Analyst in Science and Technology, Congressional Research Service, Library of Congress.

at the surface of the material by metallic contacts. The familiar example of this is the use of solar cells to power satellites.

Wind energy—The winds are caused primarily by the unequal heating of the earth's surface by the sun. Hence, wind energy is a form of solar power. Turbines turned by winds can extract the energy in moving air and generate electricity.

Ocean Thermal Energy Conversion (OTEC)—Between the Tropics of Cancer and Capricorn, where the average intensity of solar energy is at a maximum, 90 percent of the Earth's surface is water. Solar radiation heats this surface water to temperatures of up to 29° C, while water at depths below 600 meters remains cold, typically near freezing at 1.7 to 3.3° C. A heat engine can operate across this small temperature difference, though only at about 2 percent efficiency. The amount of heat in the surface water is so large, however, that even at this efficiency immense amounts of energy are available.

Bioconversion.—Conversion of solar energy into clean renewable fuels starts with the photosynthetic production of organic materials. Solar radiation causes the growth of plants and other organisms such as algae, which can be used after suitable processing (drying, chipping, or grinding) for fuel. Such organic materials can also be converted to methane, hydrogen, or oil by destructive distillation (pyrolysis), fermentation, or by high pressure chemical processing. A resulting fuel such as hydrogen may be used in a fuel cell to produce electricity, or burned directly to produce heat and electricity by standard means.

Direct thermal applications.—The collection and direct use of solar heat is applied to such tasks as the heating and cooling of building space, domestic hot water heating, greenhouse heating and crop drying in agriculture, and the augmentation of process steam generating systems in industrial applications. For most applications of this type, solar energy is captured by "flat plate" collectors. Such collectors do not concentrate sunlight; they consist merely of a black surface directed skyward and covered by one or more transparent covers to prevent loss of heat. Under the right conditions, flat plate collectors easily achieve temperatures of 100° C. Heat is extracted by circulating air or water through channels embedded in the collector's surface. The heat can be used at the time of collection or stored in simple rock bins or water tanks for later use.

Status of technologies.—The various approaches to solar energy conversion can be seen to span a wide range of technologies. Some are very well defined and are now entering the stage of commercial feasibility, others require significant research to establish commercial viability. Of the six major approaches only space and water heating systems for buildings, and photovoltaic and wind energy systems for remote electric power applications are considered marginally competitive at this time. Megawatt-capacity wind machines, larger photovoltaic systems and bioconversion systems are expected to be available and to become increasingly attractive during the early to mid-1980's. OTEC and solar thermal conversion systems are not expected to demonstrate commercial feasibility before the mid-1980's or later. Success in any one of the solar technologies will depend on meeting the criteria of technological and economic efficiency, in competition with atomic and fossil fuel power systems.

SOLAR IMPACT STUDIES

Paley report.—Perhaps the earliest commentary on the need for solar energy research was provided by the Materials Policy Commission in its report to the President in 1952, the so-called "Paley Report." [1] The Commission recognized that energy plays a key role in meeting the Nation's long-range materials needs. In commenting on the role to be played by technology, the Commission stated that one task should be:

> To develop and use more economically the resources that nature can renew * * *. The direct utilization of solar energy without the necessity for cycling it through stockpiles of fossil fuels millions of years old is perhaps the most important contribution technology can make to the solution of the materials problem.

In its analysis of solar energy, the Commission concluded:

> * * * Efforts made to date to harness solar energy economically are infinitesimal. It is time for aggressive research in the whole field of solar energy—an effort in which the United States could make an immense contribution to the welfare of the free world.

NSF/NASA study.—The Paley report provided no recommendations concerning the content or funding levels for a solar program. In recent years however several solar program plans have been issued which identify levels of funding required for effective research and development. The first, a study prepared by the NSF/NASA panel of experts, was entitled, "Solar Energy as a National Energy Resource." [2] It recommended that a 15-year program be undertaken, at a total cost to Government and the private sector of $3.5 billion. The study concluded that a substantial development program could achieve necessary technical and economic objectives by the year 2020—at which point solar energy could economically provide up to: 35 percent of the total heating and cooling load; 30 percent of the gaseous fuel; 10 percent of the liquid fuel; and 20 percent of the electric energy requirement.

AEC study.—A second major study of solar energy's potential contribution followed the June, 1973, Presidential announcement of the initiation of a $10 billion program for energy research and development extending over the next 5 years.[3]

A plan for the implementation of this program was to be developed by the Chairman of the AEC. Background studies for the master plan were undertaken by 16 subpanels working during the month of October, 1973. A report on solar energy was prepared by Subpanel IX.[4] This report estimated that 10 to 30 percent of the Nation's projected energy requirements could be provided by solar energy by the year 2000 and as much as 50 percent by the year 2020. An initial 5-year program with two alternative levels of funding was recommended: a "minimum" plan with a budget of $409.9 million and an "accelerated orderly" plan with a budget of $1.056 billion. No attempt

---

[1] William S. Paley (Chairman), "Resources for Freedom," a report to the President by the President's Materials Policy Commission, June 1952.

[2] "Solar Energy as a National Energy Resource", prepared by the NSF/NASA Solar Energy Panel, NSF/RANN-73-001, December 1972.

[3] Executive Energy Message by President Richard M. Nixon, The White House, June 29, 1973.

[4] Solar and Other Energy Sources. Subpanel IX, WASH-1281-9. Prepared for the Chairman, U.S. Atomic Energy Commission, in support of her development of a comprehensive Federal energy research and development program to be recommended to the President on December 1 1973.

was made to develop a maximum or "crash effort" plan. When the overall research and development plan [5] was submitted to the President in December, 1973, the funding recommended for solar energy was $200 million, an amount substantially below the level described as "minimum" by Subpanel IX. This was apparently due in part to the need to constrain all energy funding within the $10 billion specified by the President.

FEA study.—Following the announcement of "Project Independence" on November 7, 1973, the FEA issued a series of Project Independence Blueprint reports, including one entitled, "Solar Energy".[6] Two implementation plans for solar energy were developed: business-as-usual and accelerated. While both plans reflect Federal participation in R. & D., only the accelerated program anticipated a Federal role in commercialization. Under the accelerated implementation plan, it was estimated that the combined contribution of the six major solar technologies could reach a maximum of 0.4 percent of the Nation's total energy demand by 1980, 1.2 percent by 1985, 3.4 percent by 1990, and 21.6 percent by 2000. Under the business-as-usual plan, the solar contribution could reach a maximum of 0.1 percent by 1980, 0.7 percent by 1985, 1.8 percent by 1990, and 6.0 percent by 2000. The report cautions however that it would be very optimistic to expect all solar technologies to reach their maximum projected output. Rather, some mix of technologies will probably be implemented, resulting in a lower total annual contribution than would be indicated by the sum totals. The FEA report presented an overall program plan, but lacked complete details on funding requirements.

NSF study.—About 6 months after the release of the FEA report, NSF issued a report entitled, "National Solar Energy Program".[7] It was later established that the budget proposed in the NSF report was consistent with the solar program identified in the FEA Project Independence Report. The 5-year funding levels for the NSF plan are shown in table 29 below.

TABLE 29.—RECOMMENDED FEDERAL SOLAR ENERGY RESEARCH AND DEVELOPMENT BUDGETS

[In millions of dollars]

Source	Fiscal year— 1975	1976	1977	1978	1979
Subpanel IX:					
Minimum viable program	50.5	67.5	89.7	104.8	97.4
Accelerated program	106.4	188.9	237.2	264.4	259.8
The Nation's energy future	32.5	39.9	41.4	42.2	44.0
National solar energy program	50.0	154.8	242.4	299.0	325.8

ERDA studies.—Program plans have also been prepared by ERDA on the solar energy program and on the total Federal energy research, development and demonstration program. "Definition Report, National Solar Energy Research, Development and Demonstration Pro-

[5] "The Nation's Energy Future", a report to Richard M. Nixon, President of the United States, submitted by Dr. Dixy Lee Ray, Chairman, AEC, Dec. 1, 1973.
[6] Solar Energy. Federal Energy Administration Project Independence Blueprint, Final Task Force Report under the direction of the National Science Foundation. November 1974.
[7] National Science Foundation, "National Solar Energy Program," Dec. 1974.

gram (ERDA–49)" [8] sets forth the National Solar Energy Program as mandated by Public Law 93–473. According to estimates in this report, the future contribution of solar energy could reach 0.8 percent of the total National demand by 1985, 7 percent by 2000 and 25 percent by 2020, assuming that costs can be reduced to the point where solar energy is competitive with other fuel sources.

"A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future (ERDA–48)" [9] assesses the relative roles of all energy sources through the year 2000. This report presents six estimates of the possible contribution of solar energy to total U.S. energy requirements, each as part of a potential national energy strategy. The strategy which essentially limits nuclear power production to those plants which are already built or on order resulted in the highest potential contribution of solar energy to National energy needs: 0.6 percent by 1985 and 7 percent by 2000. The first annual update of ERDA–49, designated ERDA 76–1 (April 1976), identifies solar heating and cooling as one of seven high-priority technologies that have the potential for making significant energy contributions in the near to mid-term; solar electric, breeder reactors and fusion were identified as high-priority programs with longer-term potential.

Tabulation of solar impact studies.—For hearings on the small business and Government roles in solar energy,[10] the staff of the Senate Select Committee on Small Business tabulated the wide variety of estimates that had been made of U.S. energy consumption in future years, and of possible solar energy contributions to the National energy demand. The range of estimates of either the combined total solar contribution or the contribution of single solar technologies can be enormous, illustrating the degree of uncertainty involved in any attempt to project the future use of solar energy. The studies are fairly consistent in showing a rather small solar contribution in the near to mid-terms, but vary wildly in estimates of the solar contribution in the year 2000 and beyond. The tables, which are expressed in both quads (a quad is 1 quadrillion British thermal units) and percentage of total consumption, are reprinted in Appendix, p. 388.

THE FUTURE UTILIZATION OF SOLAR ENERGY

Uncertainty of estimates.—Solar energy has the potential to make a major contribution to the future U.S. and world demand for solid, liquid and gaseous fuels and electricity. However, the time and extent to which solar-derived power can be substituted for presently-used sources are hotly debated subjects at this time. Future impact will depend on the action and interaction of a complex array of factors including: (1) The cost of energy from non-solar sources; (2) the resolution of certain technical, economic and institutional constraints to commercialization; and (3) the energy policies (including the adoption of incentive measures) established by Federal, State and local governments. Since the outcome of these factors is extremely uncertain, the future impact of solar conversion technologies cannot be predicted with any accuracy.

[8] ERDA–49. ERDA, Division of Solar Energy, June 1975.
[9] Vols. I and II. ERDA, June 1975.
[10] See appendix.

For most solar technologies there is scant, if any documentation (industry development, sales trends) on which to base a long-range projection. Efforts to estimate even the 5- or 10-year impact are confounded by information gaps which only time can close for certain. Better estimates of future use are dependent on what can be learned from Federal and industry R&D efforts during the next few years, as well as on the timely resolution of anticipated non-technical problems.

Near to mid-term impact estimate.—There seems to be little argument that over the long-term solar will become an increasingly important source of energy. To 1990, however, there is little evidence to indicate that the combined contribution of all solar technologies will amount to more than 2 or 3 percent of the demand (2 or 3 quads). Actually, a contribution of just 1 percent (1 quad) would be a very substantial accomplishment and is probably a more realistic estimate for planning purposes.

Why not more, sooner?—At this time solar technologies are at various stages of commercial readiness. Based on cost and supply trends of presently-used energy sources, and on judgements of R. & D. still required for each solar technology, it appears possible that commerical feasibility can be determined for all solar technologies within the 1990 timeframe. The problem, is however, that even if the marketability of each solar technology is demonstrated on schedule, it is unlikely that rapid commercialization will follow. Instead, acceptance and diffusion of viable solar technologies into the U.S. energy market will probably be slow and may be long postponed.

Market penetration will be slow.—There are several reasons for suggesting that the U.S. energy industry will be slow to substitute solar technologies for presently-used energy systems. First, the industry is too heavily invested in existing systems to convert to solar overnight even if such conversion were possible, which it is not. Consider the difficulty now being experienced with getting utilities to convert their gas and oil-fired plants to coal. Compared to a solar technology, conversion to coal would represent a rather minor changeover.

Second, the huge capital requirement of a mass introduction of a solar technology will most certainly be a limiting factor. Solar powerplants are expected to have a low operating cost, but their initial cost is expected to be several times that of a fossil or nuclear plant. Utilities having trouble raising capital for a conventional plant now may find it impossible to raise three or four or more times that amount for a solar powerplant of equal capacity.

A third reason is a problem that frequently delays the introduction of a new technological innovation, particularly one which must compete with an industry as well established as the U.S. energy industry. Experience with related technology has shown that even after an innovation meets the requisite technical and economical conditions, rapid market penetration is unlikely for at least two resaons: (1) inertia in the spread of knowledge of the innovation's capabilities, plus (2) inertia in the development of a supporting industrial infrastructure for supply, installation, insurance, finance, maintenance, et cetera. This industry lag problem is already a serious one for the solar space and water heating industry. Studies show that this technology is competitive in most parts of the country where the alternative is electric space or water heating. And yet, installations are

proceeding at a very modest pace—far short of the pace necessary to produce a meaningful contribution by this technology in the near to mid-term.

Accelerating the solar market.—If solar technologies are allowed to enter the U.S. energy market on a "business-as-usual" basis, there is no reason to expect more than a slow to moderate penetration of the market over the next several years. However, it may be possible to accelerate the diffusion rate with financial and other kinds of incentives. Each of the various solar technologies may require its own set of incentives, but, if effective, such measures could sharply reduce the lag time associated with the introduction of a new technology, and thereby cut the time required for solar to make a meaningful contribution to the U.S. energy demand.

Many types of incentive options are available at the Federal, State and local government levels, each of which could promote a more rapid acceptance of solar technology where such was considered sufficiently beneficial to justify the cost. Several incentive measures are pending in the 95th Congress, including a proposal in the Administration's energy bill which calls for a tax credit on residential and commercial solar space conditioning and hot water installations. If enacted the credit would undoubtedly have an initial positive effect on the market for this particular solar technology.

Disincentives for the continued or expanded use of presently-used energy sources have also been suggested as a means for accelerating the market for solar technologies. Deregulation of the price of natural gas is an example of this kind of solar "incentive."

Another possibility is to use Federal buying power to create an immediate mass market for emerging solar technologies. A problem with solar thus far is that because of high cost demand has been too low to warrant the use of mass production techniques, but only through mass production will costs be reduced and the systems made practical. The Federal Government could foster mass production by placing very large orders for solar equipment. Again, careful cost/benefit analyses showing substantial gains for the Nation should underlie any such measure.

Numerous other incentive options are being considered. But because so little is known about user acceptance, system performance, and so many other factors, it is yet unclear what the full impact of incentives will be. For example, poor performance by a solar technology in the early stage of marketing could result in a diminished impact; better than expected performance, a greater impact. Incentives can be a valuable tool if properly applied. For maximum effectiveness, the selection and application of an incentive requires precise timing and careful consideration of the interdependent technical, economic, social and political issues involved.

The long-term impact.—Progress in dealing with the technical, economic and social factors should lead to a "coming of age" of solar-electric technologies in the years between 1985 and 2000. But because of the time and capital required to get systems on line, it is unlikely that solar-electric will begin to have an important effect on the energy supply problem until after 1990. The use of solar technology for space and water heating should increase steadily in the near and mid-terms resulting in an important contribution to the U.S. energy demand in the long-term.

CONCLUSION

While no estimate of future impact is conclusive, an estimated solar contribution of 1 percent of the total U.S. demand for energy by 1990 appears to be an attainable number. The largest contribution is expected to come from the technology for solar space conditioning and water heating. Solar-electric technologies are not expected to be commercially feasible before the mid to late-1980's, but may be contributing to the National demand in a small way by 1990. The substitution of solar-electric technologies for conventional ones may not occur on an important scale until well after 1990's due to the large existing investment in conventional systems and the large capital requirements of any solar electric technology. For planning purposes, therefore, it appears that solar-electric technologies might best be regarded a long-range option (important substitution after 1990); solar thermal technology a near to mid-term option on a limited basis, but becoming increasingly attractive over the long term.

APPENDIX

Estimates of U.S. Energy Consumption, Total and by Function, and of Solar Energy Contributions by Technology, 1980–2020.[1] A table prepared by the Senate Select Committee on Small Business. 1976.

TABLE 30

ESTIMATES OF U.S. ENERGY CONSUMPTION, TOTAL AND BY FUNCTION, AND OF SOLAR ENERGY CONTRIBUTIONS BY TECHNOLOGY, 1980–2020: 3D EDITION

	1980	1985	1990	2000	2020
I. U.S. energy consumption, total and by function, 1980–2020 (in quads *per year):					
A. Consumption of energy from all sources, for all uses:					
1. Federal Energy Administration, Project Independence Report (FEA)[1]	82.2	94.1	112.0		
2. Ford Foundation Energy Project[2]		92.0	102.0	124.0	
3. National Science Foundation/National Aeronautics and Space Administration (NSF/NASA)[3]	91.0	117.0	128.0	177.0	300.0
4. Joint Committee on Atomic Energy[4]	91.5	127.0	133.0	180.0	
5. National Petroleum Council[5]		127.0	148.0	201.0	
6. Dupree-West[6]	96.0	116.0	136.0	192.0	
7. TRW[7]	94.0	114.0	128.0	155.0	
8. Westinghouse[8]	104.0				
9. Shell Oil[9]	101.0	121.0	141.0		
10. Stanford Research Institute[10]	113.2	142.9			
11. Council on Environmental Quality[11]	97.0	123.7			
12. Energy Research and Development Administration, Creating Energy Choices for the Future (ERDA-48):[12]					
(a) No New Initiatives		107.0		165.0	
(b) Increased Efficiencies in End Use		97.0		122.0	
(c) Synthetics from Coal and Shale		107.0		165.0	
(d) Intensive Electrification		107.0		161.0	
(e) Limited Nuclear Power		107.0		158.0	
(f) Combination of All Technologies		98.0		137.0	
13. Energy Research and Development Administration, National Solar Energy Research, Development and Demonstration Program (ERDA-49)[13]		100.0		150.0	180.0
14. Federal Energy Administration, Final Task Force Report on Solar Energy (FEA)[20]	93.0	120.0	144.0	180.0	
15. National Planning Association[25]	102.6	124.9			
16. Department of Interior[26]	88.0			168.0	
17. M.I.T. Energy Laboratory Policy Study Group[27]	96.8				
18. Federal Energy Administration, National Energy Outlook (FEA)[28]	~80.0	98.9	~115.0		
19. MITRE[29]	90.0	120.0		180.0	180.0
20. Teller[19]	84.0	103.0		170.0	
21. Bankers Trust[32]	89.7	104.9	125.7		
22. Exxon, U.S.A.[33]	~85.0	~95.0	~115.0		

[1] Excerpt from hearings on Energy Research and Development and Small Business, Part 2, Solar Energy (continued): the Small Business and Government Roles. Hearings before the Senate Select Committee on Small Business, Oct. 8, 22, and Nov. 18, 1975: p. 5455–5460.

ESTIMATES OF U.S. ENERGY CONSUMPTION, TOTAL AND BY FUNCTION, AND OF SOLAR ENERGY CONTRIBUTIONS BY TECHNOLOGY, 1980-2020: 3D EDITION—Continued

	1980	1985	1990	2000	2020
I. U.S. energy consumption, total and by function, 1980–2020 (in quads * per year)—Continued					
B. Consumption of energy from all sources for heating and cooling (residential and commercial):					
1. FEA, Project Independence Report[1]	21.5	25.5			
2. Ford Foundation Energy Project[2]		22.6		36.2	
3. NSF/NASA[3]	17.0			21.0	30.0
4. Joint Committee on Atomic Energy[4]	21.0		30.7		
C. Consumption of energy from all sources or electrical generation:					
1. NSF/NASA[3]		37.0		76.0	160.0
2. Teller[10]		33.0			
3. Ford Foundation Energy Project[2]		23.2			
4. Department of Interior[26]	24.6			72.3	
D. Consumption of gaseous fuel from all sources for all uses:					
1. NSF/NASA[3]		27.0		31.0	40.0
2. Department of Interior[26]	25.8			41.7	
E. Consumption of liquid fuel from all sources for all uses: NSF/NASA[3]		50.0		63.0	80.0
II. U.S. energy consumption, by function, 1980–2020 (in percentages of U.S. total energy consumption):					
A. Consumption of energy from all sources for heating and cooling (residential and commercial):					
1. FEA, Project Independence Report[1]	26.2	27.1			
2. Ford Foundation Energy Project[2]		35.0		29.2	
3. NSF/NASA[3]	15.0			12.0	10.0
4. Joint Committee on Atomic Energy[4]	22.9		23.1		
B. Consumption of energy from all sources for electrical generation:					
1. NSF/NASA[3]		31.6		42.9	53.3
2. Teller[10]		32.0			
3. Ford Foundation Energy Project[2]		25.4			
C. Consumption of gaseous fuel from all sources, for all uses: NSF/NASA[3]		23.0		17.5	13.3
D. Consumption of liquid fuel from all sources, for all uses: NSF/NASA[3]		42.7		35.6	26.6
III. U.S. solar energy consumption, total and by function, 1980–2020 (in quads * per year):					
A. Consumption of solar energy from all sources for all uses:					
1. Joint Committee on Atomic Energy[4]				2.1	
2. ERDA—48:[2]					
(a) No new initiatives		0		0	
(b) Increased efficiencies in end use		.3		3.5	
(c) Synthetics from coal and shale		.1		1.5	
(d) Intensive electrification		.3		6.6	
(e) Limited Nuclear Power		.6		11.1	
(f) Combination of All Technologies		.4		6.3	
3. ERDA–49[13]		~1.0		~10.0	~45.0
4. FEA, Final Task Force Report on Solar Energy:[20]					
(a) Accelerated implementation Plan[22]	.4	1.4	4.9	38.8	
(b) Business as Usual[22]	.1	.8	2.6	10.8	
5. National Planning Association[35]	0	0			
6. Department of Interior[26]	0			0	
7. FEA, National Energy Outlook[28]	~.1	~.2	~.3		
8. Bankers Trust[31]	<.1	<.3	<.7		
9. Exxon, U.S.A	0	0	0		
B. Consumption of solar energy for heating and cooling (residential and commercial):					
1. NSF/NASA[3]		<2.0		2.1	10.5
2. NSF[14]		[15].1			
3. Westinghouse[3]	0	0	0	1.1	3.8
4. TRW:[7]					
(a) No Incentives				1.3	
(b) 25 percent Tax Credit Incentive				2.1	
5. Energy Research and Development Administration, National Plan for Solar Heating and Cooling (ERDA–23)[16]	0	.21			
6. General Electric[17]		.1	.2	.6	
7. Joint Committee on Atomic Energy[18]				2.1	
8. ERDA–49[13]		.2		2.0	15.0
9. Atomic Energy Commission (AEC)[21]				[26]6.3	15.0
10. FEA, Final Task Force Report on Solar Energy:[20]					
(a) Accelerated Implementation Plan	.3	.6	1.5	3.5	
(b) Business as Usual	0	.3	.6	2.3	

See footnotes at end of table.

ESTIMATES OF U.S. ENERGY CONSUMPTION, TOTAL AND BY FUNCTION, AND OF SOLAR ENERGY CONTRIBUTIONS BY TECHNOLOGY, 1980–2020: 3D EDITION—Continued

	1980	1985	1990	2000	2020
III. U.S. solar energy consumption, total and by function, 1980–2020 (in quads * per year)—Continued					
C. Consumption of solar energy for electrical generation by technology:					
1. Thermal conversion, as estimated by:					
(a) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	0	0	0	1.3	----
(2) Business as Usual	0	0	0	.6	----
(b) NSF/NASA[3]	0	0	----	.8	8.0
(c) ERDA-48[13]	0	0	----	1.1	3.8
(d) AEC[21]				.9	----
2. Photovoltaic:					
(a) NSF/NASA[3]	0	0	----	----	----
(b) NSF[14]	0	----	----	1.7	----
(c) ERDA-49[13]	0	0	----	1.6	4.3
(d) AEC[21]	0	----	----	5.4	----
(e) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	0	0	.3	7.0	----
(2) Business as Usual	0	0	.1	1.5	----
3. Wind energy conversion:					
(a) NSF/NASA[3]	0	0	----	.8	16.0
(b) NSF[14]				4.0	----
(c) ERDA-49[13]	0	0	----	1.1	3.2
(d) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	0	.5	2.0	5.0	----
(2) Business as Usual	0	.4	1.6	4.0	----
(e) AEC:[21]					
(1) Low				3.4	----
(2) High				6.8	----
(f) Inglis[30]					
4. Ocean thermal difference:					
(a) NSF/NASA[3]		0	----	.8	16.0
(b) NSF[14]				1.7	----
(c) ERDA-49[13]		0	----	.5	2.2
(d) FEA, Final Task Report on Solar Energy:					
(1) Accelerated Implementation Plan	0	0	.2	7.0	----
(2) Business as Usual	0	0	.1	1.7	----
5. Combustion of organic matter:					
(a) NSF/NASA[3]				.8	16.0
(b) FEA, Final Task Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	.1	.3	.9	15.0	----
(2) Business as Usual	.1	.1	.2	.7	----
D. Consumption of solar energy for gaseous fuel consumption:					
1. NSF/NASA[3]		.3	----	3.1	12.3
2. NSF[14]				.7	----
E. Consumption of solar energy for liquid fuel production, by technology:					
1. Chemical Reduction NSF/NASA[3]		0	----	.6	8.0
2. Pyrolysis NSF/NASA[3]		0	----	.6	8.0
IV. U.S. solar energy consumption, total and by function, 1980–2020 (in percentages of U.S. total energy consumption):					
A. Consumption of solar energy from all sources for all uses:					
1. Joint Committee on Atomic Energy[4]				1.2	----
2. ERDA-48:[12]					
(a) No New Initiatives		0	----	0	----
(b) Increased Efficiencies in End Use		.3	----	2.9	----
(c) Synthetics from Coal and Shale		.1	----	.9	----
(d) Intensive Electrification		.3	----	4.1	----
(e) Limited Nuclear Power		.6	----	7.0	----
(f) Combination of All Technologies		.4	----	4.6	----
3. ERDA-49[13]		1.0	----	6.7	25.0
4. FEA, Final Task Force Report on Solar Energy:[20]					
(a) Accelerated Implementation Plan	.4	1.2	3.4	21.5	----
(b) Business as Usual	.1	.7	1.8	6.0	----
5. National Planning Association[25]	0	0	----	----	----
6. Department of Interior[26]	0	0	0	0	----
7. FEA National Energy Outlook[28]	~.1	~.2	~.2	----	----
8. MITRE:[29]					
(a) Low	0	2.0	----	20.0	70.0
(b) High	0	4.0	----	35.0	70.0
9. Bankers Trust[31]	<.1	<.2	<.6	----	----
10. Exxon, U.S.A.[32]	0	0	0	----	----

21-616 O - 78 - 9

ESTIMATES OF U.S. ENERGY CONSUMPTION, TOTAL AND BY FUNCTION, AND OF SOLAR ENERGY CONTRIBUTIONS BY TECHNOLOGY, 1980-2020: 3D EDITION—Continued

	1980	1985	1990	2000	2020
IV. U.S. solar energy consumption, total and by function, 1980–2020 (in percentages of U.S. total energy consumption)—Continued					
B. Consumption of solar energy for heating and cooling (residential and commercial):					
1. NSF[14]		1.0			
2. Westinghouse[8]	0	.1	.3	.9	
3. TRW:[7]					
(a) No incentives				1.0	
(b) 25 percent Tax Credit Incentive				1.7	
4. ERDA-23[16]	0	.2			
5. General Electric[17]		.1	.2	.5	
6. Joint Committee on Atomic Energy[18]				1.2	
7. ERDA-49[13]		.2		1.6	5.0
8. FEA, Final Task Force Report on Solar Energy:[20]					
(a) Accelerated Implementation Plan	.3	.5	1.0	1.9	
(b) Business as Usual	0	.3	.4	1.3	
9. MITRE[29]	.01	.3		3.0	15.0
C. Consumption of solar energy for electrical generation:					
1. Thermal conversion:					
(a) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	0	0	0	.7	
(2) Business as Usual	0	0	0	.3	
(b) NSF/NASA[3]	0	0		.4	2.7
(c) AEC[21]				.5	
(d) MITRE[29]:					
(1) Low	0	0		2.0	10.0
(2) High	0	0		2.0	10.0
2. Photovoltaic:					
(a) NSF/NASA[3]	0	0			
(b) NSF[14]				1.1	
(c) ERDA-49[13]	0	0		.9	1.4
(d) AEC[21]				3.0	
(e) FEA, Final Task Force Report on Solar Energy[20]					
(1) Accelerated Implementation Plan	0	0	.2	3.9	
(2) Business as Usual	0	0	.1	.8	
(f) MITRE:[20]					
(1) Low	0	0		2.0	10.0
(2) High	0	0		5.0	10.0
3. Wind energy conversion:					
(a) NSF/NASA[3]	0	0		.4	5.3
(b) NSF[14]				.6	
(c) ERDA-49[13]	0	0		.6	1.1
(d) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan		.4	1.4	2.8	
(2) Business as Usual		.3	1.1	2.2	
(e) AEC:[21]					
(1) Low				12.5	
(2) High				25.0	
(f) MITRE:[20]					
(1) Low	0	1.0		5.0	15.0
(2) High	0	3.0		10.0	15.0
(g) Inglis[30]		10.0			
4. Ocean thermal difference:					
(a) NSF/NASA[3]	0	0		.4	5.3
(b) NSF[14]				1.0	
(c) ERDA-49[13]	0	0		.3	.7
(d) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	0	0	.1	3.9	
(2) Business as Usual	0	0	.1	.9	
(e) American Institute of Aeronautics and Astronautics:[24]					
(1) Low	0			4.0	20.0
(2) High	0			10.0	50.0
(f) MITRE:[20]					
(1) Low	0	0		1.0	10.0
(2) High	0	0		5.0	10.0
5. Combustion of organic matter:					
(a) NSF/NASA[3]				.4	5.3
(b) FEA, Final Task Force Report on Solar Energy:[20]					
(1) Accelerated Implementation Plan	.1	.1	.6	8.3	
(2) Business as Usual	.1	.1	.1	.4	

See footnotes at end of table.

ESTIMATES OF U.S. ENERGY CONSUMPTION, TOTAL AND BY FUNCTION, AND OF SOLAR ENERGY CONTRIBUTIONS BY TECHNOLOGY, 1980-2020: 3D EDITION—Continued

	1980	1985	1990	2000	2020
IV. U.S. solar energy consumption, total and by function, 1980–2020 in percentages of U.S. total energy consumption)—Continued					
D. Consumption of solar energy for gaseous fuel production (methane bioconversion):					
(1) NSF/NASA [3]		.2	—	1.8	4.0
(2) NSF [4]				.2	—
E. Consumption of solar energy for liquid fuel production, by technology:					
1. Chemical reduction, NSF/NASA	0	0	—	.4	2.7
2. Pyrolysis, NSF/NASA	0	0	—	.4	2.7
V. U.S. solar energy consumption, by function, 1980–2020 (in percentages of U.S. total energy consumption, by function, e.g. percentage of solar heating and cooling of total heating and cooling energy):					
A. Consumption of solar energy for heating and cooling (residential and commercial):					
1. NSF/NASA [3]		1.0	—	10.0	35.0
2. NSF [4]		3.7	—	—	—
3. Westinghouse [5]	0	.4	—	3.0	—
4. TRW: [7]					
(a) No incentives				3.6	—
(b) 25 percent Tax Credit Incentive				5.8	—
5. ERDA-23 [14]	.1	.8	—	—	—
6. General Electric [17]		.3	—	1.6	—
7. ERDA-49 [13]		.5	—	5.5	50.0
8. AEC [21]				30.0	50.0
C. Consumption of solar energy for electrical generation:					
1. Thermal conversion:					
(a) FEA, Final Task Force Report on Solar Energy: [20]					
(1) Accelerated Implementation plan	0	—	—	1.7	—
(2) Business as Usual	0	—	—	.8	—
(b) NSF/NASA [3]		0	—	1.0	5.0
(c) NSF [14]				1.0	—
(d) AEF [21]				1.1	—
2. Photovoltaic:					
(a) NSF/NASA [3]	0	0	—	—	—
(b) NSF [14]				2.3	—
(c) ERDA-49 [13]		0	—	2.1	2.7
(d) AEC [21]				7.0	—
(e) FEA, Final Task Force Report on Solar Energy: [20]					
(1) Accelerated Implementation Plan					
(2) Business as Usual		0	—	6.0	—
3. Wind energy conversion:					
(a) NSF/NASA [3]		0	—	1.0	10.0
(b) NSF [14]				4.5	—
(c) ERDA-49 [13]		.1	—	1.4	2.0
4. Ocean thermal difference:					
(a) NSF/NASA [3]	0	0	—	1.0	10.0
(b) NSF [14]				7.0	—
(c) ERDA-49 [13]	0	0	—	.7	1.3
(d) FEA, Final Task Force Report on Solar Energy: [20]					
(1) Accelerated Implementation Plan	0	—	—	—	—
(2) Business as Usual	0	—	—	—	—
5. Combustion of organic matter:					
(a) NSF/NASA [3]				1.0	10.0
D. Consumption of solar energy for gaseous fuel production (methane bioconversion):					
1. NSF/NASA [3]		1.0	—	10.0	30.0
2. NSF [14]				1.2	—
E. Consumption of solar energy for liquid fuel production, by technology:					
1. Chemical reduction, NSF/NASA	0	0	—	1.0	10.0
2. Pyrolysis, NSF/NASA	0	0	—	1.0	10.0

*1 quad equals 10^{15} (1 quadrillion) British thermal units (Btu).

[1] Federal Energy Administration, Project Indepence Report, November 1974, Conservation scenario, at oil price of $11/bbl.

[2] Ford Foundation Energy Policy Project, A Time to Choose, Technical Fix scenario, November 1974.

[3] National Science Foundation/National Aeronautics and Space Administration Solar Energy Panel, Solar Energy As a National Energy Resource, December 1972.

[4] Joint Committee on Atomic Energy, Understanding the "National Energy Dilemma," 1973, Fold-out "N".

[5] I bid., citing National Petroleum Council intermeduate scenario.

[6] Walter G. Dupree, Jr., and James A. West, United States Energy Through the Year 2000, U.S. Department of the Interior, December 1972.

[7] TRW Corp., Solar Heating & Cooling of Buildings, Phase O Report, May 1974.

[8] Westinghouse Corp., Solar Heating & Cooling of Buildings, Phase O Report, May 1974.

[9] Shell Oil Co., cited on p. 60 of The End of the Energy Crisis, Mitchell, Hutchins, Inc., May 1974.

[10] Stanford Research Institute, World Energy, November 1972.

[11] Council on Environmental Quality, Energy & Environment: Electric Power, August 1973.

[12] Energy Research and Development Administration, Creating Energy Choices for the Future (ERDA-48), June 28, 1975.

[13] Energy Research and Development Administration, National Solar Energy Research, Development, and Demonstration Program, Definition Report (ERDA-49), June 1975.

[14] National Science Foundation, as reported by ERDA in a letter dated June 13, 1975, from John M. Teem, to the Senate Small Business Committee.

[15] Number of quads calculated from cited source's statement of percentage only, using as 100 percent the FEA total energy estimate of 94.1 quads, note 1, supra.

[16] Energy Research and Development Administration, National Plan for Solar Heating & Cooling, Interim Report (ERDA-23), March 1975.

[17] General Electric Co., Solar Heating & Cooling of Buildings, Phase O Report, May 1974.

[18] Joint Committee on Atomic Energy, note 4, supra, fold-out "O".

[19] Teller, Edward, Energy, A Plan for Action, Report, to the Commission on Critical Choices for Americans, April 1975.

[20] Federal Energy Administration, Final Task Force Report on Solar Energy, Project Independence, November 1974.

[21] Atomic Energy Commission, Solar and Other Energy Sources, report of Subpanel IX (Alfred J. Eggers, Jr., Chairman) to the Atomic Energy Commission Chairman in support of her development of comprehensive Federal energy research and development program, Oct. 27, 1973.

[22] Number of quads calculated from cited source's statement of percentage only, using the NSF/NASA estimate of 21 quads for consumption of energy from all sources for heating and cooling, note 3, supra.

[23] Number of quads calculated by addition of estimates for different solar technologies. It should be noted that FEA assumes that development of some solar technologies may preempt the development of other solar technologies.

[24] American Institute of Aeronautics and Astronautics, Solar Energy for Earth, April 21, 1975.

[25] National Planning Association, Energy for America: The Policy Options, Looking Ahead, April 1975.

[26] Department of Interior, An Energy Model for the U.S. Featuring Energy Balances for the Years, July 1968.

[27] MIT Energy Laboratory Policy Study Group, Energy Self-Sufficiency, November 1974.

[28] Federal Energy Administration, National Energy Outlook, 1976.

[29] MITRE Corp., Systems Analysis of Solar Energy Programs, December 1973.

[30] Inglis, David Rittenhouse, Wind Power as an Alternative to Nuclear, from remarks in the Senate by Senator James Abourezk, the Congressional Record, July 14, 1975.

[31] Bankers Trust Co., Capital Resources for Energy through the Year, 1990, 1976.

[32] Exxon Co., U.S.A., Energy Outlook 1976-90, 1976.

Conversion table (definitions, comparisons):

- 1 British thermal unit (Btu)=the amount of heat energy required to raise the temperature of 1 lb of water 1°F.
- 1 Btu=1,055 joules=252 small calories.
- 1 barrel (bbl) of oil=5,800,000 Btu=6,119,000,000 joules.
- 1 kilowatt-hour (kWh)=3,412 Btu.
- 1 cubic foot (ft^3) of natural gas=1,000 Btu.
- 1 ton of coal=26,000,000 Btu.
- 1 quad=10^{15} Btu.
- 1 quad=172,414,000 bbl of oil.
- 1 quad=472,044 bbl of oil per day for a year.
- 1 quad=1 trillion ft^3 of natural gas.
- 1 quad=293,083,200,000 kWh.
- 1 quad=38,461,580 tons of coal=105,302 tons coal per day for a year.
- 1 quad=the capacity of the Alaska Pipeline for 108 days.
- 3.4 quads=the capacity of the Alaska Pipeline for a year.
- 1 quad=the energy spent by a subcompact car going 181,000,000,000 mi.
- 1 quad=the energy spent by a luxury car going 71,000,000,000 mi.
- 12.44 quads=1974 U.S. petroleum imports.
- 0.9 quad=1974 U.S. natural gas imports.

Source: Data derived, in part by arithmetic conversions of statistics stated in various units, from the sources cited in footnotes 1 through 32. Table concept by Ray Watts, Senate Small Business Committee.

International Aspects of the U.S. Energy Crisis

(By Herman T. Franssen*)

This chapter compares and analyses six major studies on the world energy outlook undertaken in 1976 and 1977.[1]

THE CARTER VIEW

The conclusion in each one of the studies generally agree with the outlook of the Carter Administration on the need to reduce foreign oil imports in the United States.

In its National Energy Plan, the Carter Administration expresses the fear that if demand for world oil is not drastically reduced, world demand will outpace world supply of oil by the middle 1980's. Even if the principal producer states are willing to supply more oil to the rest of the world, the Administration believes that these countries will not be able to supply all the increases in demand expected to occur in the U.S. and other countries by that time. World demand might push demand for Opec oil to a level of 50 million b/d in 1985, according to the Administration (29 million b/d in 1976). However, many Opec countries can no longer significantly expand production; and, in some, production will actually decline during the 1980s. Much of the incremental world demand for oil will have to be met from expanding Saudi Arabian production, but even the Saudis will not be able to increase production much beyond the late 1980s or early 1990s.

The National Energy Plan endorses the view of the well-known petroleum geologist, John Moody, who has put total world oil resources at about 2 trillion barrels. At a rate of consumption increase of only 3 percent per year (one-half of the historical rate of the post World War II era), world oil would be exhausted by the year 2020. Long before that time world oil production would have peaked and began its gradual decline.

The Carter Plan recognized the fact that physical exhaustion of oil will not actually occur; there will continue to be tertiary recovery methods (lifting of oil with the aid of chemicals) to lift more oil from existing fields, and eventually there will be substitutes from shale, coal or tar sands. The latter resources may be used primarily by the petrochemical industry because of the high cost of these resources for other purposes.

---

*Herman Franssen is a specialist in Environmental Policy at the Congressional Research Service.

[1] These studies are: Central Intelligence Agency, The International Energy Situation: Outlook to 1985, Washington, D.C., April 1977; Organization for Economic Cooperation and Development, World Energy Outlook, Paris, 1977; Workshop on Alternative Energy Strategies, Energy: Global Prospects 1985–2000, New York, 1977; United States Senate, Committee on Energy and Natural Resources, and National Ocean Policy Study, and United States House of Representatives, Committee on Interstate and Foreign Commerce, Subcommittee on Energy and Power, Project Interdependence: U.S. and World Energy Outlook Through 1990, Washington, D.C., 1977; Exxon Corporation, World Energy Outlook, March 1977; Walter Levy Consultants, An Amendment of U.S. Energy Policy, September, 1976.

The Carter Plan is based on the belief that world oil production cannot continue indefinitely at the current rate of 20 billion barrels per year or more. The world would have to add another Kuwait or Iran every two years or another Texas or Alaska every six months in order to continue to consume at current levels. The Carter Plan suggests that such finds are highly unlikely. Instead, future finds are likely to be smaller in size than the giant fields discovered in the Middle East throughout the 1950s and 1960s. Moreover, future discoveries are expected to take place in more hostile environments (oceans, ice-covered areas, jungles), where development will require more time and costs will be very high. Obviously, the National Energy Plan states, high rates of growth of oil consumption cannot be sustained.

IS THE CARTER VIEW CORRECT?

An analysis of four major studies on the world energy outlook for the next 10 to 15 years tends to support in general terms, the pessimistic world oil outlook on which much of the proposals in the National Energy Plan are based. The four studies compared in this chapter represent the views of the most important international organization of oil consuming nations (OECD's International Energy Agency), Congressional research organization (Congressional Research Service), the U.S. Central Intelligence Agency, and a private effort with participants from governments, universities and business organizations of 15 countries (Carroll Wilson's Workshop on Alternative Energy Strategies).

While each one of the four studies is concerned with all sources of energy, oil received most attention in all four. The reason for this is clear: of the four major sources of energy in the world today (oil, natural gas, coal, nuclear power based on uranium), oil is the most important and most widely used. Oil is also easier to transport than coal, it is a relatively clean fuel and has been relatively inexpensive until 1973/74, because of the availability of vast resources of the Middle East, which can be produced at little cost.

During most of the first two decades following the Second World War, there was a surplus of oil on the world market, and it was not until the early 1970s that policymakers in the industrial world became aware of pending oil shortages in the future. This growing awareness of potential future oil supply problems was caused by a number of factors:

New studies of U.S. undiscovered recoverable oil and gas resources, based on more elaborate scientific methods than earlier studies of this nature, suggested that the oil and gas resource base in the United States (the world's largest oil and gas consumer) was much smaller than previously indicated.

Very rapid growth in world oil consumption, in particular in the industrial nations, were no longer matched by equally large increases in oil and gas discoveries. The spectre of exponential oil demand growth rates running up against limited world oil supplies, was raised in a number of studies in the early 1970's.

The growing gap between energy produced and consumed in the United States resulted in escalating oil imports from Opec nations, beginning in the early 1970s. This in turn strengthened the already existing oil cartel when previous large oil surpluses on

the world market began to vanish. The power of the oil cartel has grown with the decreasing spare capacity of oil outside the Gulf states.

The producing nations with the largest spare capacity are located in the Persian (or Arab) Gulf, i.e. Saudi Arabia, Kuwait and the United Arab Emirates. The quadrupling of the price of oil following the 1973/74 Arab-Israeli war offers less of an incentive to countries with a large surplus capacity and limited capital absorptive capacity, to increase production. The world can no longer count on these countries—which control one-third of world oil reserves—to continue to increase production.

The immediate problem is not that the world will physically "run out of oil". At an annual increase in oil consumption of about 3%, world oil production is not likely to peak until the middle or late 1990s, if all key oil producing countries continue to expand production to meet world demand. The immediate problems are political and economical in nature. Will Saudi Arabia and a few other Gulf state producers with limited capital absorptive capacity continue to increase oil production to meet world demand and, if not, what will be the effects of substantially higher oil prices on the world economy?

THE CIA STUDY

The CIA in its analysis of the international energy situation to 1985, is optimistic about economic growth rates in the United States and Japan, but rather pessimistic about economic growth rates in Western Europe for the same period to 1985. The slow growth rate in Europe is related to lingering balance of payment problems and the continuing effects of the sharp rise in the price of oil in the 1973/74. The CIA projections of economic growth in the U.S. through 1985 are higher than the OECD forecasts, but economic growth rates for Japan and in particular for Western Europe are lower than official OECD projections. In its energy forecast, the CIA adjusted projected energy growth for potential conservation based on existing legislation. Energy savings are expected to range from 10–15% in the United States and 5–10% in OECD Europe and Japan.

Total energy demand for the OECD by 1985 is estimated at 100 million b/d (about 200 Quads), or about 40 million b/d less than what it would have been had the oil crisis of 1973/74 not occurred. No estimates are provided for oil demand in the developing nations. About 45 percent of the estimated OECD energy demand of 100 million b/d is projected for the United States.

On the supply side of the energy equation, the CIA projects energy supply to grow at an annual rate of 4 percent through 1980, and at between 1 and 4 percent between 1980 and 1985. The large difference between the high and the low are said to be due largely to nuclear debate in Europe and the United States. Coal production and utilization are also uncertain, but coal utilization problems will affect primarily the United States. Europe and Japan are not expected to move into coal utilization on a massive scale. Coal accounts for as much as 70 percent of the projected rise in U.S. energy production according to the CIA study. Oil production in the OECD is projected to rise by about 4–5 million b/d. Most of the increase will be from the

North Sea region. Only about 20–25 percent of the projected growth in oil production in the OECD will be in the United States.

The CIA is pessimistic about Soviet oil production potential. Production in the USSR is projected to peak in the late 1970s or early 1980s due to major technical problems in the older oil fields, and the disappointing discoveries of large new fields in recent years. Substitution of more plentiful energy sources in the Soviet Union, such as natural gas and coal, are not expected to make up for the projected shortfall in oil production. Hence, the CIA forecasts that the USSR and Eastern Europe will be importing between 3.5 and 4.5 million b/d by 1985. The repercussions are very serious for Soviet and Eastern European economic growth, and the pressures of additional Soviet demand for oil from free world sources would also add more strains to the already high demand for free world oil. Increasing U.S.-Soviet rivalry might result in the Middle East if the CIA forecast proves to be correct.

Demand for Opec Oil: The CIA report expects demand for Opec oil to reach 32 million b/d in 1977, and thereafter projects little change because of Alaskan and North Sea oil developments. Higher demand for Opec oil in 1976 and 1977 was largely due to higher U.S. imports. The CIA estimates Opec production to increase by another 2 million b/d by 1980, which will signal the beginning of a projected strong upward trend. Total demand for Opec oil is projected at 34 million b/d by 1980 and between 47 and 51 million b/d by 1985. U.S. imports would take between 20 and 30 percent of Opec oil exports in 1985. The developing countries as a group are estimated to offset much of their higher oil demand from domestic production, but much of the higher LDC production is likely to come from two countries, Mexico and Egypt.

CIA's estimate of Opec production by 1985 is among the highest of the recent energy forecasts. Even its low required Opec oil production figure for 1985—46.7 million b/d—is more than 10 million b/d higher than forecasted by the OECD, Walter Levy Consultants Corporation, and the studies by the Congressional Research Service and the Workshop on Alternative Energy Strategies (WAES). The high figure for Opec oil demand in the CIA study is 51.2 million b/d in 1985. Productive capacity of all Opec countries other than Saudi Arabia is estimated by the CIA at about 27 million b/d in 1977 and 28 to 29 million b/d respectively in 1980 and 1985. Hence, Saudi Arabia would have to supply about 12 million b/d in 1982, 13–16 million b/d in 1983, and 19–23 million b/d in 1985, to meet world demand. If any of the Opec countries other than Saudi Arabia would decide to reduce output, Saudi production would even have to be higher to meet the CIA oil demand estimate. The CIA study indicates that such high production levels for Saudi Arabia are not likely to materialize. Even if the Saudis were to reach a production of 20 million b/d—which is physically possible—they could only sustain such an output for about a decade, according to the study.

The CRS and OECD studies in particular, dispute the CIA projections on Soviet oil imports. While CRS does not disagree with the CIA on the likelihood of oil production shortfalls in the USSR, CRS does not believe that such shortfalls will automatically be translated into higher Soviet oil imports. Interfuel substitution mandatory conservation, and lower economic growth rates are more likely to occur

than projected oil imports of 3.5 to 4.5 million b/d by 1985. The CRS analysis indicates that shortfalls in Soviet oil production would already reduce Soviet earnings of foreign currency (energy exports now earn about one-third of total Soviet hard currency) significantly. To expect the Soviets to import the volume of oil projected by the CIA would mean additional burden on their already weak balance of payments position. Moreover, the historical drive in the USSR for autarchy, would conflict with a policy of dependence on foreign countries for one-third of Soviet oil consumption. Aside from the Soviet oil import forecast, the CIA analysis of world oil demand does not differ substantially from the other international energy projections described in this chapter.

OECD: WORLD ENERGY OUTLOOK

The OECD forecast of energy demand and supply of the OECD nations is based on in part of contributions made by member governments, supplemented by an in-house analysis by the staff of the International Energy Agency. It is the second major energy demand/supply forecast by the OECD/IEA (the earlier study was published in 1975), and has proved to be much better than the 1975 effort. The 1975 study was tailored along the lines of the American "Project Independence", and failed to convince most energy analysts who had been unable to "buy" the Project Independence approach in the United States. The 1977 study gained significantly from the independent analysis of energy demand and supply undertaken by the IEA staff.

Following the 1974–75 recession in the OECD region, economic growth rates projected for the period through 1985 have been revised downward in the 1977 IEA/OECD annual average real growth of GNP of 5.1 to 4.1 percent per year. Lower GNP growth rates are said to be in part caused by higher prices for energy. Energy growth rates are projected to decline in the region from an average annual of 5.1 percent for the period from 1960–1973, to no more than 3.6 percent per year in the period from 1975–1985. Higher energy prices and mandatory conservation efforts are projected to lower the energy/GDP ratio from 0.99 in 1960–73, to 0.84 for 1975–85. Oil consumption is estimated to decline even faster than total energy growth rates, from 6.7 percent annually from 1960–74, to 3.1 percent between 1975 and 1985, and its share in total energy consumption is projected to decline from 51 percent in 1974 to 49 percent in 1985. Natural gas consumption is projected to grow from 17 percent in 1974 to 20 20 percent in 1985 in the OECD region, and coal utilization is estimated to decline from 20 percent in 1974. Only in the United States is coal utilization expected to grow significantly. Nuclear power is projected to grow most rapidly, from 2 percent of total OECD energy consumption in 1974 to 9 percent by 1985.

Oil and Gas Production

Prior to the middle 1970s, the United States was the only major oil producing state in the OECD. Following the discovery of North Sea oil in the British and Norwegian sectors, the major expansion in oil production in the OECD is expected to come from the North Sea. While Alaskan oil will be produced at a rate of 1.2 million b/d

as early as 1978, most of the increased Alaskan oil production will be offset by lower production from the Lower 48 States in the U.S. Japan is not likely to ever become a major oil producer in the foreseeable future.

Oil production is OECD Europe was 0.4 million b/d and is projected to be at 3.5 million b/d in 1980 and 4.3 million b/d by 1985. U.S. production of 10.4 million b/d in 1974 (including NGL) increases to 10.8 million b/d in 1980 and 11.6 million b/d in 1985 in the OECD study. Japanese oil production is projected to continue to be negligible. Natural gas production in Western Europe is projected to rise from about 5.5 trillion cubic feet in 1974 to approximately 7.8 TCF in 1980 and 8.0 TCF in 1985. By contrast, U.S. natural gas production is estimated to decline from 20.9 TCF in 1974 to 17.5 TCF in 1980, after which it would increase again to 19.2 TCF by 1985. Japanese production of natural gas is expected to remain negligible. Western European oil production could be increased if Norway were to undertake a more vigorous development program. In view of that Nation's policies towards development, production is not likely to reach a level of 1 million b/d by 1985.

Coal Production

Coal production declined from 334 million tons of oil equivalent (Mtoe) in the OECD in 1960 to 206 Mtoe in 1974. For the OECD as a whole, the study projects a slight production increase to 217.8 Mtoe in 1980, and much of the increase is projected from the U.S., Spain and Turkey. French and German coal production are estimated to continue to decline, but at a slower pace than before. Environmental costs, labor issues and security of foreign supply of coal for utilities are among the issues affecting the low coal utilization projections from France and Germany. Japanese coal production is expected to follow a somewhat similar path leading to stabilization of coal production in that country. Net imports of all coal are projected to increase by one-third in Japan and Western Europe. In the United States, the OECD study projects coal utilization to follow the path spelled out in the National Energy Outlook of 1976: increased production from 620 million short tons in 1974 to a projected 799 million tons in 1980 and 1,039.3 million tons in 1985. The OECD is optimistic about the coal conversion program in the United States, and expects that environmental problems will be overcome by FEA ruling to grant variances from emission standards. Such variances would in fact only legalize the de facto variances and therefore not represent an additional stimulus.

Nuclear

The OECD study projects that much of the energy supply increases in the OECD during the next decade will come from nuclear power. Ever since the Arab oil embargo, European governments have focused on nuclear power as the one source of energy that could be increased rapidly enough to serve as a replacement for imported oil. It should be noticed here that the lead-time from initial licensing to electricity production from nuclear power plants is much lower in Europe and Japan than in the U.S. where lead-times are now more than ten years.

Total nuclear power capacity in OECD-Europe is projected to increase to 55.5 GWe in 1980 (fourfold increase over 1974) and to 114.6 GWe in 1985. An accelerated nuclear power development program could add another 24.3 GWe to this figure. In Japan, an even more rapid increase in nuclear power is forecasted. The base case estimates nuclear power capacity in Japan in 1985 at 35.1 GWe; the accelerated case would raise this to 49 GWe. Even the lower figure would represent a tenfold increase over 1974.

Oil Imports

Assuming demand and supply of energy in the OECD will follow the projected course during the period through 1985, oil imports in 1985 would rise to 9.7 million b/d in the United States (7.2 million b/d in 1976); 14.7 million b/d in Western Europe (14.1 million b/d in 1974); and, 8.8 million b/d in Japan (5.3 million b/d in 1974). Demand for Opec oil from other parts of the world was estimated at 6.1 million b/d by 1985. Total demand for Opec oil would reach 39.3 million b/d in 1985, out of a productive capacity of 45.0 million b/d for all of Opec. Hence, physical surplus capacity could be as high as 5.7 million b/d by 1985. Spare capacity of oil might still be as high as 11.5 million b/d in 1980, but of this total volume, about two-thirds would be held by Saudi Arabia. The Saudis and other producer states may continue to to develop excess capacity, because the price of maintaining excess capacity is low, and some excess capacity may be intentionally planned in the hope that it will confer political power. The OECD study does not go so far as to predict that producer countries will indeed be willing to meet projected world demand for oil by the middle 1980s. Beyond the middle 1980s, OECD oil imports are projected to continue to rise to 40.5 million d/b, or 5.5 million b/d more than in 1985. At this rate all surplus capacity would have vanished. In the OECD accelerated energy development scenario, oil imports in the region could be kept at 27.2 million b/d, which is about the same as the region's 1973 imports of oil.

Variations on a Theme

If economic growth increases more rapidly than projected in this study, or if growth lags behind these projects, energy demand could be affected in a major way. It is important to understand that if economic growth in the OECD will in fact be a half percent higher or lower than the average annual 4.2 percent assumed in the reference case, oil imports may deviate 5 to 10 million b/d in either direction from the above 1990 estimate. On the supply side of the equation, additional large oil and gas discoveries in the North Sea or U.S. frontier areas, uncertainty about the nuclear and coal options, or breakthroughs in alternative energy sources, may all impact on actual oil import requirements during the period for which projections are made. In fact, internal IEA studies already suggest that the nuclear power projections in this study may have been too optimistic. Moreover, recent studies on U.S. oil and gas production, and estimates on coal utilization in the United States through 1985, also suggest that additional supply shortfalls are likely in the United States. On the other hand, slow economic recovery in Europe is likely to hold energy demand down in that part of the world.

CRS: PROJECT INTERDEPENDENCE

Project Interdependence focuses on U.S. energy demand and supply through 1990, and depends heavily on the OECD analysis of European and Japanese demand/supply projections discussed in the previous section.

Three demand scenarios were developed for the United States: a low, medium, and high energy demand scenario. All depend on the market system, with prices of oil and gas rising rapidly through the period projected. The CRS demand forecasts do not analyze the potential effect of Btu taxes on energy demand. U.S. average economic growth is projected at 3.5 percent in the base case and the optimistic case; 3.4 percent in the pessimistic case. Prices for energy sources differ in each of the demand scenarios, and unemployment ranges from 5.4 to 5.7 percent throughout the next fifteen years. The economic forecasts resulted in energy demand projections of between 104.5 and 113.4 quadrillion Btu's (Quads). The reference case estimates demand at 94.8 Quads in 1985 and 108.9 Quads in 1990. Conversion losses are calculated at about 24 Quads in 1985 and 29 Quads in 1990. The biggest growth is projected for the industrial sector of the economy, with little growth projected for the household and commercial sectors. The study suggests that a gradual Btu tax, leading to a tax of $1.35 per million Btu's by 1990 could reduce average annual demand growth to about 2 percent (down from 2.9 percent in the base case and 2.5 percent in the low demand case), but the effects of such a tax on GNP growth and employment cannot be predicted.

On the supply side of the energy equation, the CRS study projects oil in the United States to increase from about 10 million b/d in 1976 to 10.9 million b/d in 1985 and 11.4 million b/d by 1990. Natural gas is projected to continue to decline slowly, from 20.3 TCF in 1976 to 16.9 TCF in 1985 and 1990. Both oil and gas projections in the CRS analysis assume decontrol and no changes in the outer continental shelf leasing system.

Nuclear energy is projected to grow from a current capacity of about 50 GWe (gigawatts) to 130 GWe in 1985 and 330 GWe by 1990. The major constraint on nuclear power capacity growth is the licensing system. The CRS study assumes that licensing will be speeded up to achieve the projected capacity.

While the National Energy Plan relies heavily on coal utilization to fill much of the potential energy gap in the United States, the CRS study is less optimistic about both demand and supply of coal. Numerous constraints related to environmental enhancement efforts, manpower, organization, transportation, government policies, labor, and other problems, are likely to have an adverse effect on efforts to increase coal utilization in the U.S.

The projected 1,200 million short tons of coal production in the U.S. by 1985 (current production is below 700 million tons), could fall 200 to 300 million tons short of the target, according to the CRS study. Moreover, the CRS study maintains that since the late 1960s, the Btu value of coal mined in the United States has decreased steadily. The CRS study points out that in order to get to a coal production of 940 million short tons by 1985, perhaps as much as 35 percent will have to consist of low-Btu Western Lignite. This, in turn, will bring

the average Btu value of coal mined in the U.S. further down than projected in the National Energy Plan. By contrast, coal shipped abroad will be primarily high-Btu metallurgical coal. By taking this into account, CRS arrived at a domestic U.S. coal utilization figure significantly below the projections on the National Energy Plan.

Oil Imports

Annual energy demand growth of 2.9 percent in the CRS base case, will result in total U.S. energy consumption of 94.7 Quads in 1985. Out of this CRS has calculated that 67.6 Quads will be produced from domestic sources, and about 27 Quads would be imported. Natural gas imports are expected to double to about 2 TCF (0.99 TCF in 1976) and oil imports would rise from 7.2 million b/d in 1976 to 11.8 million b/d by 1985 (plus 0.3 million b/d for the oil storage program).

CRS based OECD demand for Opec oil on the recent OECD World Energy Outlook, and adjusted the figures for projected shortfalls in nuclear power capacity in Western Europe and Japan. Oil import figures for developing non-oil-producing states were based on a modified analysis of the OECD projections for those countries. The CRS analysis is less optimistic about developing countries' ability to substitute other fuels for oil at the rate projected by the OECD. Hence, CRS estimates higher oil imports for those nations for the year 1985. On the other hand, the CRS study is more optimistic on inter-fuel substitution in Opec countries. The CRS study assumes that much of the energy growth in Opec countries, and in particular in the Middle East, will be based on natural gas. Hence, CRS projects lower oil consumption for Opec nations than either the OECD or the CIA studies.

CRS has made a detailed analysis of projected physical productive capacity of oil production in the free world, and compared these data with projected world oil consumption. The study concluded that at projected world oil growth rates of about 3 to 3.5 percent per year, no physical oil production gap is likely to develop throughout the period studied (1990). Having said that, CRS maintains that there is no way to predict how much oil will actually be produced during the 1980s, and subsequently it is difficult, if not impossible, to project what will happen to world oil prices.

Two principal factors affecting world oil prices will be: (1) Aggregate world oil demand; and, (2) The level of oil production of Saudi Arabia and a few other smaller Arab Gulf producers.

If the industrial world succeeds in holding demand for Opec oil down to current or slightly higher levels, world oil prices are likely to remain stable. If, as projected in the CRS base case, world demand for Opec oil were to grow significantly above 35 million b/d, key oil producers like Saudi Arabia, would have to produce more than 15 million b/d by the middle 1980's. It is highly questionable that the Saudis will produce at such high levels, and it would be politically unrealistic—if not dangerous—to count on it. It is clear that if world demand for Opec oil will reach the levels projected by CRS, and if Saudi Arabia refuses to increase production beyond a certain level not known today, world oil prices will rise. When, and by how much, cannot be forecasted with any degree of certainty. The CRS study questions the willingness of Saudi Arabia to produce 16.6 million b/d

in 1985 and 20.6 million b/d by 1990, as called for in its world oil demand supply scenario for the following reason: Assuming that Saudi Arabia will find 2 billion barrels of oil per year between now and 1990; at the projected output and new reserve additions, the current reserve/production (R/P) factor would decline from today's 50 years to about 17 years by the year 1990.

At that time, Saudi Arabia will still not be a mature industrial or commercial power. Education, organizational, and other bottlenecks which stand in the way of economic development, cannot be removed entirely in 15 years.

By 1990, Saudi Arabia is not likely to have diversified its economy sufficiently to eliminate or significantly reduce its dependence on oil revenues. In the meantime, the country would have exchanged an extremely valuable resource in the ground for treasury bonds of industrial nations and direct investments in an uncertain world. With its limited population and insignificant military posture, the Saudis may not be able to bring enough pressure to bear on the industrial world to guarantee protection of its legitimate interests in those countries. Hence, unless the industrial world succeeds in limiting demand for oil significantly in the years to come, or succeeds in harnessing new technologies resulting in vast quantities of environmentally acceptable sources of energy cheaper than oil, the only possible reason for continued expansion of Saudi oil production is related to internal and external security of the kingdom.

The CRS study shares the concerns expressed in the CIA, OECD, and WAES/MIT studies, that for a variety of political and economic reasons, world oil production might peak long before the physical limits of production are reached. The CRS study provides a number of suggestions to entice the Saudis to increase oil production, and concludes that efforts to bring about lasting peace in the Middle East are most certainly the most important step to achieve that goal.

W. J. LEVY CONSULTANTS CORP., AN ASSESSMENT OF U.S. ENERGY POLICY

This study focuses on domestic U.S. energy demand and supply. The study does provide some data on world energy demand and supply. It projects world consumption of energy to increase by some 46 million b/d oil equivalent to 133 million b/d oil equivalent in 1985.

The United is estimated to account for the largest single part of the increase, about 14.5 million b/d. After the contributions of nuclear power and coal, U.S. consumption would increase by 7.4 million b/d, accounting for half of the total increase in energy requirements and being the largest single increment in world oil consumption.

The increase in Western European energy consumption (about 11.8 million b/d oil equivalent) is also projected to involve a large increase in oil consumption of 6.5 million b/d. But, two-thirds of Europe's increased oil consumption is estimated to be met by its own expanded oil production, notably from the North Sea.

Japan in particular will have to meet by far the largest part of the increase in total energy requirements (estimated at 7.3 million b/d oil equivalent) by increased oil consumption (4.6 million b/d). Apart from Japan's nuclear program, increased consumption of coal and natural gas will also largely depend on imports.

On balance, the United States would also show the largest increase in oil imports (4.9 million b/d). In effect, the 10-year increase in U.S. import requirements would account for almost a third of the 1975–1985 expansion in Opec oil exports.

This study is the only one of the six studies analyzed which provides some insight into the economic costs of continued dependence on foreign oil. Assuming, as this study does, that the price of oil will increase by 5 percent per year (the assumed rate of inflation), the estimated F.O.B. cost of net oil imports in all free world consuming countries is projected to rise from $106 billion in 1975 to $169 billion in 1985 (in constant dollars), or from $106 billion in 1975 to $281 billion in 1985 if calculated in current dollars. For the United States, the cost of oil imports are estimated to increase from $23 billion in 1975 to $42 billion in 1985 in constant dollars, or from $23 billion in 1975 to $70 billion in 1985 in current dollars. This would represent one-fourth of the world cost for imported oil.

U.S. oil import costs in real terms (constant 1975 dollars) would almost double by 1985 reflecting the large projected increase in oil import requirements. Western Europe would not have so large an increase in the real cost of oil imports owing to the substantial part of increased oil consumption that will be met by incoming North Sea production.

SHELL OIL CO., THE NATIONAL ENERGY OUTLOOK 1980–1990

This study, published in September 1976, focuses on domestic energy demands and supply, but towards the end of the published summary report, a world oil production scenario is added.

The Shell study projects U.S. economic growth rates averaging 4.7 percent per year from 1975–1980, and 3.1 percent per year from 1980 through 1990. The study also assumes the environmental concerns will prevent optimum development of all forms of energy; that demand reductions by either market price or governmental mandate will be approached slowly; and that capital formation problems will constrain energy development. The forecast also assumes that by the 1980s, domestic oil production will rise to world market levels, and regulated interstate natural gas prices will increase significantly.

Throughout most of the forecast period, oil-producing nations are assumed to provide adequate supplies to meet both U.S. and foreign import needs. In the 1985–1990 period, world oil demands are likely to strain limits defined by the exporter's willingness to produce.

Energy demand growth rates are said to decline from about 5 percent in the period from 1965–1970 to two to three percent annual average increase from 1970–1990. This reflects both higher prices, conservation measures, and lower population growth. Total energy consumption is estimated at 41.6 million b/d oil equivalent (about 88 Quads) in 1980, 48.1 million b/d of oil equivalent in 1985 (about 101.8 Quads), and 55.2 million b/d by 1990 (about 116 Quads). Of this total, oil demand is projected at 20.3 million b/d in 1980, 21.9 million b/d in 1985 and 23.3 million b/d by the year 1990. The biggest expansion in oil demand is projected for the industrial sector.

From 1975–1980, oil consumption is estimated to grow at three percent per year; and between 1980 and 1990 at only one percent per year.

Domestic supply of oil is forecasted at just above 10 million b/d in 1980, below 11.5 million b/d in 1985, and at about 13 million b/d by 1990. Synthetics are projected to contribute 0.3 million b/d in 1985 and 1.0 million b/d by 1990. These figures are already included in the earlier quoted domestic oil supply figures. Domestic natural gas supply is projected to decline from just about 20 TCF in 1973 to about 17 TCF in 1980, by close to 0.9 TCF in 1985, and 1.6 TCF by 1990. Most of the syngas in 1985 and 1990 would come from coal (about ⅔ in 1985 and ¾ in 1990).

Coal demand and supply are projected in b/d oil equivalent only. In view of the difference in Btu content of Eastern and Western coal (bituminous coal and lignite) coal demand and supply in short tons per year cannot be calculated from the data in the report. Domestic coal demand is projected at about 7.5 million b/d oil equivalent in 1980, 9 million b/d in 1985, and 12.5 million b/d oil equivalent by 1990. The quoted coal demand includes coal for gasification and liquefaction (about 0.1 million b/d oil equivalent in 1980. 0.3 million b/d oil equivalent in 1985, and close to 0.8 million b/d oil equivalent by 1990).

Nuclear power capacity is projected to grow from about 0.4 million b/d in 1973 (oil equivalent) to 2 million b/d in 1980, 4 million b/d in 1985, and close to 9 million b/d oil equivalent in 1990.

The difference between projected energy demand and domestic supply is made up by imports of oil and gas, which are expected to grow from 6.7 million b/d in 1973 (of which about 0.5 are natural gas imports) to 11.2 million b/d oil equivalent in 1980 (of which about 1.2 million b/d oil equivalent are for natural gas); 11.8 million b/d in 1985 (of which about 1.2 million b/d oil equivalent are for natural gas); and, 11.3 million b/d by 1990 (of which about 1.2 million b/d oil equivalent are for natural gas).

Given the assumptions of decontrol, the domestic oil and natural gas projections in the Shell analysis are not unrealistic but may prove to be somewhat too optimistic. Coal utilization appears realistic, but nuclear power projections seem too high for 1985 and certainly for 1990. Total domestic supply in the Shell forecast would appear to be too optimistic in comparison with more recent estimates, but on the other hand, total U.S. energy demand also appears a few million b/d higher than most recent studies would suggest. On balance, the oil and natural gas imports volumes would therefore still appear realistic.

World Oil Production

Shell projects a free world oil production of about 59 million b/d in 1980; 65 million b/d in 1985; and, about 74 million b/d by 1990. In comparison with several recent studies these figures seem realistic, and within the range of world physical capacity.

EXXON: WORLD ENERGY OUTLOOK

This study is the 1977 edition of Exxon's annual projection of world energy demand and supply. Like the other studies analyzed in this chapter, Exxon writes that it is clear that the world has entered a

period of transition in the sources and uses of energy. In contrast to the past when shifts were made to fuels which were either lower in cost or more convenient, the next 15 to 20 years will be a period of accelerated depletion and rising real costs of the energy forms now in use. We face significant risks, according to the Exxon study, that supplies will not be readily available to meet all demands. And if serious problems are to be avoided beyond this period, development must accelerate now on the new sources that will be essential to meet the needs of the 1990s and beyond.

In its 1977 World Energy Outlook, Exxon made the following assumptions: approximately constant real world prices of oil; slower future world economic growth; international stability and cooperation; substantial conservation and energy supply measures in the industrial countries; and, Opec capacity expansion and production to meet world oil needs.

Real economic growth rates for Europe, Japan and the United States (the OECD region) are projected to decline from an annual average of 4.7 percent in 1965–73, to 4.3 percent during 1975–80 and 3.7 percent during the decade of the 1980s. Energy demand is projected to decline from an annual increase of 5.1 percent between 1965–73, to 4.0 percent for 1975–80, and 3.1 percent for the decade of the 1980s. The implied conservation in the OECD region would be 9 percent by 1980, 13 percent by 1985 and 17 percent by 1990 (i.e. 17 percent less energy consumption by 1990 than without conservation efforts).

The 17 percent lower energy demand caused by conservation translates into a potential savings of 22 million b/d, or the equivalent of Middle East oil production in 1976. About one-half of those savings would take place in the United States.

World Energy Supply

World energy growth is projected to grow from 85 million b/d oil equivalent in 1975 to about 157 million b/d oil equivalent in 1990. This growth is much below what was projected before the crisis in 1973. About two-thirds of the reduction is said to be the result of slower projected economic growth, and about one-third the result of conservation.

Much of the energy growth projected for the next 15 years will have to come from energy sources other than oil. Since World War II, oil has, for reasons of economics, convenience, and availability, taken the lion's share of energy growth. In the years before the 1973–74 Arab-Israeli war oil grew at about twice the rate of non-oil energy supplies. In the future, these rates are expected to be reversed as efforts to accelerate the development of other supply sources bear fruit. Exxon projects oil supply to grow at 5.5 percent per year between 1975 and 1980 (1965–73: 7.7 percent) and to decline to 2.5 percent per year between 1980 and 1990. Non-oil supply growth rates are projected to grow at 4.1 percent per year between 1975 and 1980 (3.2 percent for the 1965–73 period) and 5.2 percent annually between 1980 and 1990. Of the non-oil energy supply sources, nuclear energy is projected to grow fastest on a world-wide scale, with its contribution increasing from the present 2 percent level to 11 percent by 1990—a growth rate of 17 percent per year. Coal is expected to reverse its historic decline and begin to grow again at about the rate of total energy, thus maintaining its 19 percent

21-616 O—78——10

share of the market. Coal expansion will be higher in the United States.

Other sources of energy, including hydropower and solar are projected to grow only slowly during the next 15 years, and in terms of a percentage of total energy supply, alternative energy sources are not expected to grow. Natural gas is not expected to grow as rapidly as it has historically, and its share of world energy supply is projected to decline from 19 percent today, to about 15 percent in 1990. Synthetic fuels from coal, shale, tar sands and very heavy oils may become a significant industry in the late 1980's but they are not expected to supply more than 1 percent of 1990 requirements.

In the final analysis, Exxon maintains that while non-oil energy sources are expected to double in volume by 1990, they will still account for only 52 percent of energy supply versus 47 percent today. As a result, growth in oil supplies continues to be needed to balance world energy demand. Because of the long lead times needed to reverse coal's historic decline and to build a substantial nuclear contribution, oil continues to increase its share from the present 53 percent of world total until the early 1980's, when it is projected to decline. By 1990, oil will still supply 48 percent of total world energy supply.

The Exxon analysis is probably still too high on nuclear power capacity in Europe and the United States in 1985 and 1990, although the authors of the study already revised their earlier estimates further downward in view of projected lower demand for electricity, and because of institutional problems related to uncertainties about various aspects of the fuel cycle. The world coal outlook also appears to be rather optimistic, in particular as far as the United States is concerned, where constraints on demand and supply of coal are likely to reduce the contribution this source is projected to make to energy supplies.

Exxon's analysis of world oil supply through the 1990, based on existing reserves and reserve-addition projections of no more than 15 billion barrels per year, appear very realistic in comparison with other studies. Exxon maintains that without political constraints on the supply of oil the world can probably count on sustained growth in oil production for perhaps only another 15–20 years. In its analysis Exxon does not examine any of the political questions which may affect world oil supplies.

In view of the optimistic free world supply scenario, Exxon still projects a small spare capacity throughout the period of its forecast. The study concludes, however, that whether or not the levels shown for 1990 are reached a few years earlier or later, the outlook implies very little flexibility to deal with major unexpected developments in trends of energy demand or supply.

The implications are clear, according to the study. Lead times for conventional and non-conventional sources are energy supply between 5 and 12 years from inception to commercial production. The only short term option Exxon foresees is production from discovered Mid-East reserves (short term is defined as the period through 1985). While supplies through the middle 1980s are already largely determined, beyond 1985 new sources can make a significant contribution if technological, economic and policy development are actively pursued from this time on.

Implications

Exxon believes that economic growth rates are going to be lower than the rates we have grown accustomed to in the industrial world. Actual growth are said to depend very much on government policy and consumer responses to the new energy environment. On non-Opec energy supply, Exxon emphasizes uncertainty of supply forecasts, and uncertainties related to government policy, and environmental questions. Oil is projected to remain the marginal source of world energy supply, and the major source remains the Arabian peninsula. The policies of Saudi Arabia are key, and remain a major source of uncertainty in the outlook. Ongoing depletion of conventional energy reserves, calls for development of new energy sources for the 1990s.

In the transition period, reliance on Opec oil will increase, which calls for cooperation with oil producing nations. Effective conservation measures are absolutely necessary to reduce energy demand in order to reduce the risk that the terms of energy supply availability will largely determine economic growth rates. Finally, the actual and potential conflicts between energy and environmental needs must be resolved.

ENERGY: GLOBAL PROSPECTS 1985–2000 (MIT/WAES STUDY)

This comprehensive study based on contributions from 30 participants from 15 energy consuming and producing nations representing about 80 percent of world energy demand and supply, projects energy demand and supply through the year 2000. The project leader of the study was Professor Carroll L. Wilson from the Sloan School of Business at the Massachusetts Institute of Technology.

Major Conclusion of the Study.

World oil supply will run short sooner than most people realize. Unless appropriate remedies are applied soon, the demand for petroleum in the non-communist world will probably overtake supplies between 1985 and 1995. That is the maximum time we have: thirteen years, give or take five. It might be less. Petroleum demand could exceed supply as early as 1983 if the Opec countries maintain their present production ceilings because oil in the ground is more valuable to them than extra dollars they cannot use. There is not much time to learn how to replace or decrease our dependence on the fuel that for three decades has fed the expansion of Western living standards and the hopes of all nations for material betterment. Time is our most precious resource. It must be used as wisely as energy.

The MIT/WAES study developed a number of energy demand/supply scenarios based on different assumptions of price, economic growth, development of energy sources, institutional obstacles, and public response to the crisis. The five major scenarios developed in the study are primarily designed for learning more about basic strategic choices, and the kind of adjustments that are needed. Of the five major scenarios in the study, only one—D3—appears to close the gap between demand and supply. All others show gaps between "desired demand" and supply of energy in the free world. The study makes clear that in the real world no such gaps exist, but that demand/supply inbalances translate into higher energy costs, which in turn have an effect on economic growth and employment.

Like the preceding studies, the WAES study projects that without any constraints on supply other than physical ability to produce, world oil production is likely to peak during the middle 1990s. Potential supplies of oil, however, are dependent on political and economic factors as well. It is quite feasible that after the middle 1980s the gap between demand and supply of oil will widen rapidly. Most WAES scenarios do in fact project this kind of a course, even if 15 billion barrels of oil are discovered in the world every year. WAES suggests that every effort should be made to move to alternative energy sources such as coal and nuclear power. Oil should be reserved for the transportation and feedstock sectors.

Conservation

Energy conservation, says the WAES study, must be a starting point for rational energy policies. It may very well be the best of the energy choices available, and must play an important role in global and national strategies to the end of the 20th century and beyond. Zero or near zero growth in total primary energy use would be extremely difficult to achieve worldwide by the year 2000, but some countries may succeed in reaching this target. For the world as a whole, zero growth is a more realistic target after the turn of the century, according to the WAES study.

Higher prices and active conservation policy could reduce the energy/GNP growth ratio for the world from 1.02 for the recent 1965–72 period to 0.82 to 0.87 during the remainder of this century. In the industrial countries of Western Europe, Japan and North America, the decline in energy/GNP ratio is projected to be more significant than for the free world as a whole, because the potential for conservation is greater in the industrial countries.

Demand for Energy in the Free World

Energy demand in the free world was 4.4 percent per year between 1950 and 1972. WAES projects energy demand to decline to between 2.6 and 3.5 percent per year for the remainder of the century. The WAES study does not include a base case or reference case, but case C (C1 after 1985) has been called the "hoped for future" by Professor Wilson. Electric demand rates are projected to decline from recent historical growth rates of 7.5 percent to between 3.8 and 5.1 percent per year through the year 2000. The growth rates represent unconstrained or desired demand, depending on whether or not energy supplies will be available to meet the demand. When imports of fuels are constrained by global supply potentials, the study indicated that even these levels of electricity demand cannot be met.

Total demand for primary energy is projected to rise from 80.2 million b/d oil equivalent in 1972 to 123.2 million b/d oil equivalent in 1985 (C Case). A lower demand scenario, based on lower economic growth rates, estimates total energy demand at 114.1 million b/d oil equivalent by 1985. Total world demand by the year 2000 is projected between a low of 159.9 b/d oil equivalent and a high of 206.8 million b/d of oil equivalent, depending on economic growth rates, energy prices and government policy. The "hoped for future" case—C1—projects a demand of 197.9 million b/d oil equivalent.

The fastest growing sector in the world economy is the industrial sector, followed by transportation and residential and commercial uses.

Demand/Supply Balances

WAES maintains that in all but one case, world energy supply can meet world demand until the middle 1980s.

Natural gas reserves and resources on a worldwide basis are unlikely to limit production in the next 25 years. The U.S. may be the only major producer facing sharp production declines in the more immediate future. Worldwide problems are related to transportation, distribution and export policy of major producers. The C and D scenarios in the WAES study estimate natural gas demand to grow from 15.1 million b/d oil equivalent in 1972 to between 18.4 and 21.0 million b/d oil equivalent by 1985. The U.S. is projected to import about 1 million b/d oil equivalent in 1985 (about 2 TCF/year) and 2.8 million b/d oil equivalent (5.6 TCF/year) by the year 2000.

Nuclear energy in the free world is estimated to grow from an installed capacity of 66.9 gigawatts in 1974 to between 291 and 412 gigawatts in 1985 and between 913 and 1,172 gigawatts by the year 2000. The high figure would mean an annual growth rate of 14 percent for the next 25 years. The maximum supply scenario would permit nuclear energy to supply as much as 21 percent of the world's primary energy by the year 2000. This is equal to about 45 million b/d of oil, or as much energy as is contained in all of the free world's oil production in 1975 (or 3 billion tons of coal). The WAES study did not address itself to the public policy debate on nuclear power, but merely projected growth potential on the basis of technical feasibility. TheWAES study concluded, however, that uncertainties surrounding nuclear power projections are greater than for any other fuel. Extended delays on nuclear power programs in various countries could hold nuclear power to the levels projected for 1985, which are based on commitments and construction already underway in most cases.

Coal

Coal could be a major "gap-filler" for many countries, but will it? The WAES study projections of desired coal demand show that total coal use will be well below the level that energy-consuming countries would have to reach to avoid an overall energy supply gap. WAES shows that with coal—as with oil—there is a major conflict between desire and reality; but the conflict produces opposite effects. National preference for oil produce a prospective shortage. National distaste for coal produces a potential surplus. The WAES projections for coal production are between 1,463 million tons and 1,680 million tons in 1985 (Cases C and D), and between 2,042 million tons and 3,169 million tons (Case C1 and D8) for the year 2000. This compares with a production of 1,073 million tons in 1972. In all cases the United States would have to produce 50 percent or more of total free world coal production (about the same as current percentage). Recognizing the technical, environmental and institutional problems related to coal utilization, the WAES study projects desired coal use will be well below the level that energy consuming countries would have to reach to avoid an overall energy gap. To meet the coal challenge head-on in the free world, there must be guarantees that coal will be available to meet potential world demand, and potential users must be convinced that coal can be burned cleanly.

Oil

If there were no supply constraints, WAES suggests that demand for oil in the free world could rise to between 58 million b/d (low growth scenario) and 63 million b/d (high growth scenario) in 1985. By the year 2000, oil demand in the free world could rise to between 75 million b/d (low growth scenario) and 93 million b/d (high growth scenario). Even the high growth scenario of 3.4 percent annual increase in oil demand to 1985, and 2.6 percent from 1985 to the year 2000, is well below the historical growth rate of 6.2 percent (1960–1972).

Where is the oil supposed to come from? WAES projects a non-Opec production in 1985 of 22.0 to 24.7 million b/d. To meet world oil demand, Opec would have to produce between 36 and 41 million b/d. If Opec were to decide to limit oil production to less than 36 million b/d, there will be a shortfall in 1985, but if Opec increases supply to more than 41 million b/d, demand and supply will be in balance. The latter figure, however, may require a Saudi oil production of close to 15 million b/d. Moving closer to 1990, the demand/supply balance will be more serious. Non-Opec oil supply by the year 2000 is projected to be slightly lower than 1985 supplies. Hence, any increases in world oil demand would have to be met by increased Opec production. The C1 ("hoped for future") case estimates non-Opec free world oil production at 24.6 million by the year 2000. Total "desired" demand for oil was estimated at between 75 (low) and 93 (C1 case) million b/d, leaving a demand for Opec oil of between 50.4 and 68.4 million b/d. It is unlikely that even the lower demand figure can be met. Hence, WAES concludes that potential oil demand in the year 2000 is unlikely to be satisfied by crude oil production from conventional sources. Oil production could peak as early as the early 1980s (caused by government policy of supplier nations) or as late as the early 1990s. The end of the era of growth in oil production is probably at the most 15 years away.

The WAES study has been optimistic on oil reserve additions in its C1 (hoped for future) case, but even if high additions to oil reserves are calculated into the demand/supply equation (20 billion barrels per year or the equivalent of two North Slopes per year), Opec would still be required to supply 39 million b/d in 1985, 47 million b/d in 1990, 57 million b/d in 1995, and 56 million b/d by the year 2000. WAES adds that it is possible that unprecedented additions to oil reserves are made (more than 20 billion barrels per year), but even such an unlikely occurrence would only delay the impact for a few years rather than solve the problem of transition to other fuels. WAES concludes that for nations to continue to increase their consumption of oil in the hope that more optimistic estimates might prove to be correct is to run the real risk that the peak in oil production could be brought forward, making the necessary adjustments in energy consumption patterns much more severe.

CONCLUSION

Given the almost infinite choice of assumptions entering into an analysis as complex as a forecast of world energy demand and supply, it is very interesting and revealing that six major recent energy forecasts compared in this chapter show a great deal of unanimity in their projections.

Each one of the six studies agrees that the world has entered a new era in energy development; a gradual transition away from an economy based on oil, to an economy based on a variety of other fossil fuels (gas and coal) and energy sources. There are obvious differences in projected economic growth rates for various parts of the world and on the effects of higher prices and mandatory conservation on the energy/GNP ratio in various parts of the world. There are differences in view on estimates of the contribution nulcear power and coal are likely to make to fill the energy gap created by already stagnating oil production in some major supply countries or by projected peaking of world oil production at some point within the next three decades. Soviet oil production and its effect on world oil demand has been another area of controversy. The CIA study indicates that serious technical problems in older oil fields in European Russia will result in lower Soviet oil production, beginning as early as the late 1970s or early 1980s. Lower Soviet oil production will force the Soviets to purchase between 3.5 and 4.5 million b/d by the middle 1980s, thus compounding the already serious problem of potential imbalance between oil demand and supply. None of the other studies has said that the CIA is wrong in its analysis of the production problems in Soviet oil fields in European Russia. They do, however, question whether lower Soviet oil production can be automatically translated into higher imports from the Middle East or other oil exporting nations.

The CRS study maintains that a combination of mandatory conservation policy, a possible speed-up in offshore drilling activities, more interfuel substitution (coal and gas for oil), and possibly even lower economic growth rates, may be more realistic than to expect the Soviets to spend much of their precious foreign exchange on oil. It is also possible that the Soviet Union and Eastern Europe may decide to allocate much more resources to the energy sector of the economy than hitherto had been expected. If such a domestic policy might be supplemented by Western credits and access to Western oil exploration and development equipment, the Soviet Union may succeed in solving much of its supply problems, It should also be noted that most sources indicate that the Soviet Union is in very good shape as far as resources of liquid hydrocarbons are concerned. Most oil geologists believe that if there is another Middle East in the world (in terms of oil resources), it can only be in Siberia. Soviet long-term oil and gas problems may well be small compared to the U.S. situation.

Taking into account differences in economic growth projections, the studies compared in this chapter do not show a great deal of difference in total world energy demand for the period to 1985. Demand projections for Europe, Japan and the United States are not too much apart, and those areas count for about 75 to 80 percent of free world energy demand. The differences in total world demand between the six studies appear to be largely related to estimates of energy demand for the developing countries. The MIT/WAES study has undoubtably spent more effort on developing an energy demand model for developing countries than any of the other six studies. Developing countries' energy demand projections in the MIT/WAES C case (hoped for future) for 1985 are about 22.3 million b/d oil equivalent. The other five studies project energy demand in the developing countries in 1985 at between about 20 and 35 million b/d oil equivalent.

The major difference in oil production forecasts in the OECD region are related to United States. Oil production projections for the United States range from 9.9 million b/d to 13.0 million b/d for 1985. Projections for Western Europe range from 4.3 to 5.1 million b/d for 1985.

World oil demand reflects in part expectations of the contributions other energy sources are likely to make to total supply, because oil remains the swing fuel, filling the gaps between total energy demand and supply. The OECD study, which is rather optimistic on nuclear power and coal utilization in that region, projects total free world demand for oil at 61.5 million b/d. CRS and Exxon, on the other hand appear less optimistic on the contribution from those energy sources. Their projections of free world oil demand are respectively 66.9 (CRS) and 67.5 (Exxon) for 1985. The CIA study projects the highest demand for free world oil, between 68.3 and 72.6, but this forecast includes Soviet oil imports of free world oil of between 3.5 and 4.5 million b/d. Aside from the projected Soviet oil demand for free world oil, the CIA forecast of free world oil demand does not differ much from the other studies.

Each one of the studies projects significantly higher U.S. oil imports in 1985 than is projected in the National Energy Plan. The Plan is an attempt to reduce U.S. oil imports in 1985 to between 6 and 7 million b/d. The above studies project U.S. oil imports in 1985 at between 9.7 and 15.6 million b/d.

All of the above studies, however, agree with the National Energy Plan, that the United States accounts for the largest growth in demand for Opec oil, and that given its energy resources and large potential for conservation, the United States must reduce its dependence on imported oil. The projections of 1985 U.S. oil imports in the above studies are between 2.5 and 8.4 million b/d higher than actual 1976 imports. While all agree that Opec has the physical capacity to continue to supply the world with all the oil it needs (even under the most pessimistic CIA scenario) until at least the middle 1980s, they also agree that for policymaking purposes we cannot and should not count on Opec nations with a large spare capacity to continue to fill the gap between world demand and supply for oil. Hence, long before the world will reach its physical oil production capacity, Saudi Arabia and a few other Gulf nations which control about one-third of the world's oil reserves, may freeze or even reduce output. In view of the long lead times required to fill the gap between desired demand for oil and production and utilization of other energy sources, such a move is likely to cause a rise of world oil prices. While stimulating development of alternative energy sources, the immediate affect of such a move is likely to be adverse on both economic growth and employment.

The studies analyzed in this chapter also appear to agree that even if the Arab Gulf states were to continue to increase oil production to physical capacity, production of conventional oil is likely to peak sometime in the 1990s. Ceteris paribus, a Saudi decision to meet world demand by continued expansion of oil output until physical capacity is reached, would keep prices down and limit development of

synfuels. Hence, if current oil prices do not move upward in real terms, private enterprise is not likely to commit itself to large-scale commercial development of synfuels without some form of government support. A technological breakthrough resulting in competitive prices of synfuels would change this situation.

Implicitly or explicitly, each one of the studies compared here agree that limitations on known and projected conventional oil resources, will make transition to more plentiful fossil fuels and other energy sources necessary. All agree that at world oil consumption growth rates of 3.5 percent (about one-half of historical growth rates), the best we can hope for is that world oil production will peak sometime in the 1990s, but political factors may reduce the transition period. Lead time required to shift to coal, nuclear power, synfuels, solar and other alternative energy systems are such that no time should be lost to begin the massive shift of resources to develop alternative energy sources on a worldwide scale to guarantee a gradual and smooth transition from too much reliance on conventional oil to a variety of other fossil fuels and other energy sources.

The studies compared in this chapter are but a few of the many published recently in the United States and abroad. A careful analysis of the assumptions underlying most of the studies not analyzed here would confirm much—if not most—of the key issues addressed in this chapter. These are: there is not yet in the foreseeable future a major constraint on total fossil fuel resources in the world. The world's current reliance on conventional oil—a relatively easily and inexpensively exploitable resource—will have to come to an end within a few decades at best. While plentiful resources of coal, shale oil, uranium and other fossil fuels do exist, long lead times from conception of technology to large scale commercial production in an environmentally acceptable way, requires a massive commitment of resources.

The major challenge for the United States, Europe and Japan is not only to recognize the problems, but to make the commitment to solve them in a joint effort. The easy way out is to ignore the problem for as long as Saudi Arabia and the few other Opec countries with large spare capacity are willing to expand output. Growing production of Alaskan oil in the United States and North Sea oil in Europe could provide a temporary oil glut which could further aggravate the existing lethargy in the industrial nations of the West. Then, at some point in the early or middle 1980s, Opec countries with significant spare capacity may decide that it is in their interest to freeze oil output at time when North Sea production will rise slower than Europe's demand for oil, and U.S. oil production may have reached its final peak. Higher oil prices following such a decision by the Saudis could reduce economic growth in the industrial world. At such a time it may be more difficult to muster the resources needed to develop other energy sources. Moreover, in view of the long lead times required to develop alternative energy sources, it would take years before new energy sources could be counted on to replace dwindling oil production.

TABLE 31.—COMPARISON OF 5 MAJOR RECENT STUDIES (1977) ON THE INTERNATIONAL ENERGY OUTLOOK THROUGH 1985

	CIA		CRS (Ref. case)		OECD (Ref. case)		Levy	Exxon
Average annual economic growth rates, 1976–85 (percent):								
West Europe	3.4		3.8		3.8		NA	3.7
United States	4.5		3.5		3.9		NA	3.9
Japan	6.0		6.3		6.3		NA	5.1
	1980	1985	1980	1985	1980	1985	1985	
Energy demand (million barrels per day crude oil equivlent):								
West Europe	27.0–27.8	31.8–33.2			28.0	34.0	35.0	34.3
United States	42.0–43.1	48.2–50.4	40.4	44.8	40.5	48.1	48.7	48.3
Japan	9.0– 9.3	12.1–12.7			9.3	12.4	14.2	10.7
Total, free world						126.5	119.0	129.8
Domestic oil production (million barrels per day):								
West Europe	3.7	4.0–5.0	3.2	4.6	3.5	4.3	5.0	5.1
United States	10.0	10.0–11.0	10.4	10.9	10.8	11.6	13.0	9.9
Japan	0	.1	0	(1)	.07	.07	(1)	(1)
Oil demand (million barrels per day):								
West Europe	13.7–14.7	15.8–18.2	14.9	18.8	14.9	18.0	19.6	18.2
United States	19.3–20.7	22.2–25.6	20.4	22.9	19.8	21.0	23.7	22.7
Japan	6.2– 6.6	8.1– 8.8	6.4	8.6	6.4	8.2	9.4	7.1
OPEC	3.0	4.0	1.4	1.9	2.3	3.5	12.1	17.2
Non-OPEC LDC's	8.5	12.0	7.2	8.7	5.3	6.2	12.1	17.2
Canada	2.2– 2.4	2.9– 3.5	2.2	2.5	2.2	2.4	12.1	2.3
Other DC's	1.4	1.9	1.4	1.9	1.9	2.2	12.1	
Total free world demand (storage excluded)	54.9–56.7	68.3–72.6	54.8	66.9	52.8	61.5	64.8	67.5
Oil storage			1.9	1.9				
Oil imports (million barrels per day):								
West Europe	10.0–11.0	10.8–14.2	11.7	14.2	12.4	14.7	14.6	
United States	9.3–10.7	11.2–15.6	10.0	11.8	9.3	9.7	10.7	
Japan	6-2- 6.6	8.0– 8.7	6.4	8.6	6.9	8.8	9.4	
Required OPEC production	32.9–34.7	46.7–51.2	34.6	42.8	33.5	39.3	[2] 41.9	41.6

[1] Negligible.
[2] OPEC export only.